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TRANSPORTATION RESEARCH RECORD

Journal of the Transportation Research Board, No. 2238

Freight Operations 2011

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A Peer-Reviewed Publication

TRANSPORTATION RESEARCH BOARD
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TRANSPORTATION RESEARCH RECORD

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Contents

Foreword

The 2011 series of the *Transportation Research Record: Journal of the Transportation Research Board* consists of approximately 990 papers selected from 3,900 submissions after rigorous peer review. The peer review for each paper published in this volume was coordinated by the committee acknowledged at the end of the text; members of the reviewing committees for the papers in this volume are listed on page ii.

Additional information about the *Transportation Research Record: Journal of the Transportation Research Board* series and the peer review process appears on the inside back cover. TRB appreciates the interest shown by authors in offering their papers, and the Board looks forward to future submissions.

Note: Many of the photographs, figures, and tables in this volume have been converted from color to grayscale for printing. The electronic files of the papers, posted on the web at **www.TRB.org/TRROnline**, retain the color versions of photographs, figures, and tables as originally submitted for publication.

Measurement Conversion Factors

To convert from the unit in the first column to the unit in the second column, multiply by the factor in the third column.

Customary Unit	*SI Unit*	*Factor*
Length		
inches	millimeters	25.4
inches	centimeters	2.54
feet	meters	0.305
yards	meters	0.914
miles	kilometers	1.61
Area		
square inches	square millimeters	645.1
square feet	square meters	0.093
square yards	square meters	0.836
acres	hectares	0.405
square miles	square kilometers	2.59
Volume		
gallons	liters	3.785
cubic feet	cubic meters	0.028
cubic yards	cubic meters	0.765
Mass		
ounces	grams	28.35
pounds	kilograms	0.454
short tons	megagrams	0.907
Illumination		
footcandles	lux	10.76
footlamberts	candelas per square meter	3.426
Force and Pressure or Stress		
poundforce	newtons	4.45
poundforce per square inch	kilopascals	6.89

Temperature

To convert Fahrenheit temperature (°F) to Celsius temperature (°C), use the following formula:
°C = (°F – 32)/1.8

SI Unit	*Customary Unit*	*Factor*
Length		
millimeters	inches	0.039
centimeters	inches	0.394
meters	feet	3.281
meters	yards	1.094
kilometers	miles	0.621
Area		
square millimeters	square inches	0.00155
square meters	square feet	10.764
square meters	square yards	1.196
hectares	acres	2.471
square kilometers	square miles	0.386
Volume		
liters	gallons	0.264
cubic meters	cubic feet	35.314
cubic meters	cubic yards	1.308
Mass		
grams	ounces	0.035
kilograms	pounds	2.205
megagrams	short tons	1.102
Illumination		
lux	footcandles	0.093
candelas per square meter	footlamberts	0.292
Force and Pressure or Stress		
newtons	poundforce	0.225
kilopascals	poundforce per square inch	0.145

Temperature

To convert Celsius temperature (°C) to Fahrenheit temperature (°F), use the following formula:
°F = (°C × 1.8) + 32

Abbreviations Used Without Definitions

AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACRP	Airport Cooperative Research Program
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASTM	American Society for Testing and Materials (known by abbreviation only)
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
IEEE	Institute of Electrical and Electronics Engineers
ISO	International Organization for Standardization
ITE	Institute of Transportation Engineers
NASA	National Aeronautics and Space Administration
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
RITA	Research and Innovative Technology Administration
SAE	Society of Automotive Engineers
SHRP	Strategic Highway Research Program
TCRP	Transit Cooperative Research Program
TRB	Transportation Research Board

Evaluating Pricing Strategies for Storage in Import Container Terminals

Sergi Saurí, Jordi Serra, and Enrique Martín

In most container terminals around the world, storage space is scarce, and pricing policies are needed to increase performance. Specifically, congestion when inbound containers are temporarily stored in terminal yards leads to high operational costs. This paper focuses on the introduction of a yard storage tariff to encourage early pickup of containers. Different from previous approaches, the price schedule introduced has a nonzero flat rate. Both demand reactions and changes in pickup decisions are considered in the analysis. A model is developed for the objective function (profit of the terminal operator). A numerical example illustrates an optimal price schedule, shows how sensitive the profit is to the basic constituents of the model, and provides general pricing rules.

Seaports have experienced tremendous growth rates in the past decades. Particularly, container trade is estimated to have grown by a factor of five during the past 20 years and is forecast to more than double by 2020 and exceed 371 million 20-ft equivalent units (TEUs) (*1*). Containership size has increased too, adding extra pressure to the terminals servicing them. The average carrying capacity of new containerships exceeds 3,000 TEUs, with the largest containerships approaching 14,000 TEUs (*1*). Because of the growth of container trade, ports and terminals focus their efforts to increase productivity and efficiency, and to achieve optimal capacity (*2*).

The increase in container handling requires enlarged storage capacity, although in most container terminals around the world the available space is quite limited, causing congestion problems. The response to congestion problems is twofold: operative improvements (revising strategies) and tariff schemes (dissuading long-term storage).

Dwell time—the duration of stay for a container in a terminal before shipping (exports) or leaving by rail or road transport (imports)—is an indicator of terminal efficiency. The higher the dwell time, the lower the efficiency will be (*3*). The terminal throughput (volume of handled TEUs per year) can increase by including new technologies and improving existing ones (mechanization in cargo handling, information exchange), increasing storage density, blocking containers, and extending gate hours (*4*). Storage density, or yard storage productivity, can increase by optimally applying storage strategies.

Storage strategies define how containers should be allocated in the yard to minimize the number of rehandling movements and optimize operational handling costs. For imports, segregating and nonsegregating strategies were introduced by De Castilho and Daganzo (*5*) and studied in depth by Huynh (*4*) and Kim and Kim (*6*). Authors such as Taleb-Ibrahimi et al. (*7*), Kim and Bae (*8*) or Kim and Park (*9*) focus on export storage strategies, where the marshaling area is organized to minimize future movements in the loading process.

Average dwell time in Europe's main ports ranges between 4 and 8 days. In the ports of Hamburg and Bremen, Germany; Rotterdam, Netherlands; and Antwerp, Belgium, it is about 6.4 days for import and 4.6 days for export cargo. Dwell time in the Italian ports of La Spezia and Gioia Tauro is higher than their Northern European counterparts, and averages 7.4 days for vessel-to-truck and 5.6 for truck-to-vessel, appendix 7B (*10*). Overall dwell time in the Port of Los Angeles, California, is approximately 4 days for loaded containers, while in Asian ports such as Singapore and Hong Kong it is about 2 to 3 days. In the case of transshipment, average dwell time ranges from 3 to 4 days (*11*).

To reduce dwell time for imports, terminal operators try to persuade shippers and owners of the goods transported to pick up containers earlier. In most container terminals around the world, a storage fee is applied and the longer the container remains in the terminal, the more the terminal operator will charge.

The charging scheme can adopt different formulations, such as linear in the storage time after a free-time limit (an initial period during which a container may be stored without charge). The main variation in price schedules relies on the duration of this free time. It is customarily accepted as 3 to 5 days (*12, 13*) but, even in the most important European ports (see Table 1), it varies from 3 to 30 days, as the case of the Port of Zeebrugge, Belgium. Table 1 shows little consistency in demurrage policies, indicating that often terminals do not price according to their costs but rely on commercial policies or indirect charges instead.

Off-dock warehouses are also available to temporarily store containers, but, unlike the terminal yard, they have less capacity constraints and are remotely located. These auxiliary storage facilities have lower fees than the terminal yard (although higher transportation costs), and thus customers might prefer to move the containers to an auxiliary warehouse instead of paying the yard storage fee.

A few researchers have dealt with price schedules for yard storage and the analysis of demand (*15–18*). De Castilho and Daganzo (*15*) demonstrate how efficient pricing schemes can be for a variety of situations aiming to avoid the abusive use of temporary storage areas and show that optimal shed pricing policies are affected by the capacity of sheds, user characteristics, and availability of auxiliary warehouses. Shippers' behavior and costs are examined when storage rent price functions change, and a savings function is defined. Given a storage price function, the shipper is assumed to choose the duration of stay that maximizes its savings. Both nondiscriminatory

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TABLE 1 Storage Charges and Free Time at Major European Container Terminals (14)

Terminal	Free Time (days)	Charged Time (days)	Cost per TEU-day
Southampton (U.K.)	6	7–13	8.00 GBP
		14–19	16.00 GBP
		20+	18.00 GBP
Rotterdam (ECT)	9	10–16	4.83€
		17–23	10.35€
		24+	12.78€
Hamburg (HHLA)	3	4+	N/A
Bremerhaven (Eurogate)	4	5+	9.50€
Zeebrugge (OCHZ)	30	31+	1.04€
Antwerp (Dry)	5	6+	1.17€

NOTE: N/A = not available; U.K. = United Kingdom; GBP = British pound sterling; ECT = Europe Container Terminals; HHLA = Hamburger Hafen und Logistik AG; OCHZ = Hesse Noord Terminal; dry = dry bulk terminals. 1 GBP = \$1.55 and 1€ = \$1.33 in 2010 U.S. dollars.

and variable price functions are applied. Total savings and costs are evaluated in two scenarios, use of container yard storage and use of off-dock warehousing. Shipper's behavior is illustrated through demand, which can be considered as deterministic or stochastic.

Holguín-Veras and Jara-Díaz (*16*) analyze consistency of optimal pricing policies with space allocation. Space allocation and the pricing scheme are taken as a joint problem subject to the capacity constraint (determined by the space in the yard). In Holguín-Veras and Jara-Díaz (*17*) this model is generalized by making the arrival rates dependent on the terminal storage charge.

Kim and Kim (*18*) propose optimal storage pricing for import containers. The charge is based on the free-time limit and the variable storage charge (depending on the time spent in the terminal). Customers face two storage-and-delivery schedules (delivery describes the moment when a customer of the terminal intends to pick up a container). One schedule is defined by stacking at the container yard and then delivering directly to the consignee. The other schedule involves storing at the container yard only for the free-time limit, then moving to an off-dock warehouse and stacking for another period of time before delivery. Optimal prices for three administration schemes are considered: profit-maximizing terminal, profit maximization subject to a minimum service level, and minimization of the total public cost.

This paper determines an optimal yard tariff (with an initial nonzero flat rate and a time-dependent rate, a more general approach than those found in the literature) for a profit-maximizing terminal and examines how demand and storage decisions are affected by the tariff and provide pricing guidelines accordingly. This result is achieved by modeling an import terminal with regular vessel unloadings and scarce storage space.

The mathematical model states the assumptions and the notation used. Customers' choices are analyzed next. Charging a tariff affects customers' decisions in two ways: the number of containers using the terminal is reduced and the picking-up time is altered—some of the containers will prefer off-dock warehouse storing after a short period in the terminal yard. The possible delay suffered by customers is modeled. The cost and revenue models for the yard operations are introduced, concluding with the objective function (profit for the terminal operator). Fixed costs are not integrated in the objective function.

A numerical case study is presented: an optimal price schedule is obtained for a hypothetic case, and a sensibility analysis is developed (providing guidelines on how the tariff should adapt to changes in fundamental variables of the problem). Conclusions and suggestions for further research are also offered.

THE MODEL

Problem Statement and Assumptions

Suppose a number of cargo vessels (N) arrive within a time span (T) at a terminal with a temporary storage yard whose total capacity of containers is Γ. The number of containers unloaded per vessel is n, delivered by the customers at a certain rate (see Figure 1). A price (P) is charged to each container for the operations taking place in the terminal, regardless of its use of the yard. The purpose of the model is to study the effects of a tariff for yard storage and to find out which price scheme a profit-maximizing terminal should apply.

General assumptions of the model are as follows:

- The terminal operator maximizes profit for a cycle of N unloadings, a time-horizon planning introduced by Kim and Kim (*6*). Containers from previous cycles do not interfere (cycles are spanned enough).
- The terminal has some degree of market power (oligopolistic scenario).
- Containers, if an agreement is made with the terminal before unloading, can be picked up right after their unloading without being charged the yard tariff. This assumption has operative consequences: for instance, these containers could be stored (for less than one day) in a temporary buffer yard within the terminal.
- A continuous distribution of delivery times approximates the actual discrete process, as seen in Figure 2. As suggested by Watanabe (*19*), an exponential function is used. With $t-[i-1]T$ being the time since the ith unloading, the expression for the containers remaining at the storage yard (in absence of a tariff) will be

$$f^i(t)=\begin{cases} ne^{-\beta(t-[i-1]T)} & \text{if } t\geq[i-1]T \\ 0 & \text{if } t<[i-1]T \end{cases} \qquad i=1,\ldots,N;\beta>0 \quad (1)$$

where β is the rate of delivery (and $1/\beta$ the mean delivery time).

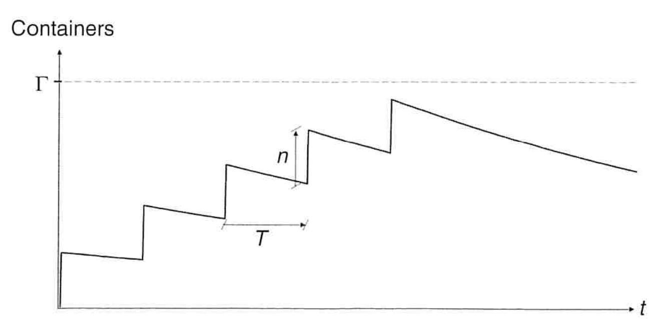

FIGURE 1 Terminal yard storage in cycle of N = 5 unloadings (Γ = temporary storage yard container capacity, t = time since loading, T = time span, n = number of containers unloaded per vessel).

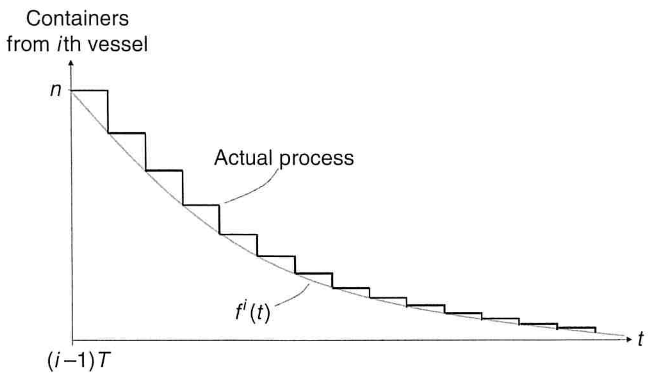

FIGURE 2 Delivery times after ith unloading [$f^i(t)$ = containers remaining at storage yard in absence of tariff, $(i-1)T$ = containers from ith vessel].

- Both unloading and delivery times are considered deterministic.
- A linear tariff with a flat-rate part is charged to the containers in the terminal yard,

$$\tau(t)=\begin{cases} a & \text{if } t \le \bar{t} \\ a+b(t-\bar{t}) & \text{if } t > \bar{t} \end{cases} \qquad a, b, \bar{t} \ge 0 \tag{2}$$

where $\bar{t}$ is the duration of the flat rate ($\bar{t} = 0, 1, \ldots$ days) and t is the time since the unloading.

- Each customer can store containers in an off-dock warehouse until delivery (picking up the container from the terminal yard and storing it off dock for another period of time). All warehouses offer the same costs for customers:

$$c(t) = c_0 + c_1 t \tag{3}$$

where t is the time spent in the warehouse and $c_0 > a$ and $0 \le c_1 < b$ are assumed: the warehouse fixed cost for customers is higher than the fixed part of the tariff, and vice versa for the variable amount. The fixed part, c_0, includes transportation from the terminal, handling, and storing.

The following sections introduce the main functions describing customer behavior and terminal costs and revenue.

Customer's Choice

In the example of a terminal customer with an unloaded container and with the yard storage priced according to Equation 2, the customer has two options: storing the container in the yard until delivery time and picking up the container and moving it to an off-dock warehouse until its delivery. Depending on the container delivery time, one option will be more profitable than the other because customers with large delivery times will prefer off-dock warehousing (see Figure 3). Combining Equations 2 and 3 provides the threshold time (t_p) at which a customer would be indifferent between the two alternatives:

$$\tau(t_p) = c(t_p) \Rightarrow t_p = \frac{c_0 - a + b\bar{t}}{b - c_1} \tag{4}$$

Customers with delivery time less than t_p will prefer to pay the tariff and keep the container at the terminal yard until delivery—their duration of stay remaining unchanged, following the original delivery distribution seen in Equation 1. Those with delivery time greater than t_p will pick up the container before delivery and pay the warehouse cost instead. The rest of this section deals with the pickup rescheduling of these customers.

Rescheduling of Pickup Decisions for Customers Storing Off-Dock

Early pickup of some containers to be stored off dock will be delayed (due to imperfect coordination, queues, etc.), being stored temporarily in the yard—at least until the flat rate finishes. The delay will never exceed an upper limit (t') such that, at delivery t, warehousing cost plus the tariff evaluated at t' will match the tariff (see Figure 3).

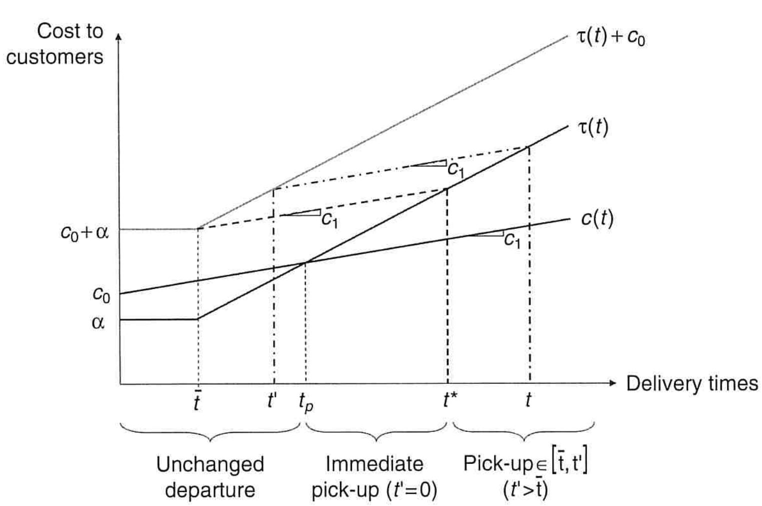

FIGURE 3 Customers' costs (paying the tariff or the warehouse cost) and departure decisions.

Then, the following relationship gives the upper limit as a function of the original delivery time:

$$\tau(t)=\tau(t')+c_0+(t-t')c_1 \Rightarrow t'=\begin{cases}0 & \text{if } t_p<t<t^* \\ t-\dfrac{c_0}{b-c_1} & \text{if } t\geq t^*\end{cases} \tag{5}$$

that is, customers with delivery time $t_p < t < t^*$ pick up the container immediately after unloading (they cannot afford delays) and those with $t \geq t^*$ suffer some delay. t^* is given by

$$\tau(t^*)=\tau(\bar{t})+c_0+(t^*-\bar{t})c_1 \Rightarrow t^*=\begin{cases}\dfrac{c_0}{b-c_1}+\bar{t} & \text{if } a>c_1\bar{t} \\ t_p & \text{if } a\leq c_1\bar{t}\end{cases} \tag{6}$$

As can be seen in referring to Equation 5, t^* is relevant only when larger than t_p (otherwise all customers with $t < t^*$ would remain at the yard until delivery), so

$$t^*-t_p>0 \Rightarrow \frac{a-c_1\bar{t}}{b-c_1}>0 \Rightarrow a>c_1\bar{t} \tag{7}$$

provides the threshold in Equation 6.

The following describes how customers willing to use off-dock warehouses before delivery (those with delivery time t_p or greater) will reschedule container pickup. On the one hand, as previously stated, customers with $t_p < t < t^*$ do not use the terminal yard at all, moving the container to the warehouse immediately. Depending on the fixed part of the yard tariff and the warehouse cost, this kind of customer may exist, as Equations 6 and 7 illustrate.

On the other hand, customers with delivery $t > t^*$ suffer some delay. This delay is assumed to follow a uniform distribution between the end of the flat rate and the maximum delay given in Equation 5, $U(\bar{t}, t')$. As the point estimate of the rescheduled pickup (t_τ), the expected value is used (as a function of the delivery time t, or pretariff pickup):

$$t_\tau=E\left[U(\bar{t},t')\right]=\frac{(t'+\bar{t})}{2}=\frac{1}{2}\left(t-\frac{c_0}{b-c_1}+\bar{t}\right) \tag{8}$$

where Equation 5 is plugged in. Uniform distribution is applied for simplicity, and an empirical study of delay times could provide a better choice, although any symmetric distribution would lead to the same result (since the expected value is used). Rearranging Equation 8 gives a transformation from each new pickup time to the delivery (or pretariff pickup):

$$t(t_\tau)=\frac{c_0}{b-c_1}+2t_\tau-\bar{t} \tag{9}$$

This transformation will be used in the next section because it allows for obtaining the position of a rescheduling customer (t_τ) in the original delivery distribution (t).

Timing of Cargo Stored in Terminal

To analyze the costs and revenue sources of the terminal, it is necessary to have an expression for the quantity of containers in the terminal yard at each time. If no storage tariff were to be charged, the occupation of the yard would be the sum of (1) for all shipments (see Figure 1): $\sum_{i=1}^{N} f^i(t)$. When a tariff is introduced, each f^i decreases because some customers stop using the terminal, maybe moving to another one, and because of the alteration of pickup decisions.

The first can be thought of as a decline in shipment volume. Most studies on terminal yard tariffs assume container arrivals to be constant on the price while some authors consider them to be elastic (*17*). Here the demand is assumed to be reduced when a tariff is introduced, but not drastically because the terminal operator has some market power. The magnitude of the reduction depends on the tariff imposed relative to the price of the total terminal operations (P). An "effective tariff" is the tariff minus the off-dock warehouse variable cost (capturing the premium charged with respect to the warehouse cost). This effective tariff is evaluated at a representative value of f^i (the mean delivery time, $1/\beta$, plus $\bar{t}$) and divided by P (the price charged regardless of yard usage). Hence the demand for the terminal is reduced by a fraction:

$$\alpha(a,b,\bar{t})=\frac{\tau\left(\dfrac{1}{\beta+\bar{t}}\right)-c_1\left(\dfrac{1}{\beta+\bar{t}}\right)}{P}=\frac{a+(b-c_1)\left(\dfrac{1}{\beta+\bar{t}}\right)}{P} \tag{10}$$

The second source of reduction arises when terminal customers change their pickup decisions once a tariff is introduced (as discussed in the previous section). In particular, those customers with delivery time $t > t^*$ get the pickup distribution of Equation 1 transformed by Equation 9, obtaining their new pickup distribution:

$$\bar{f}^i(t)=\begin{cases}0 & \text{if } t<t^* \\ f^i\left(\dfrac{c_0}{b-c_1}-\bar{t}+2t\right) & \text{if } t>t^*\end{cases} \tag{11}$$

Thus, the after-tariff number of containers in the terminal yard (see Figure 4) is

- Between unloading and the end of the flat rate ($\bar{t}$): α times the distribution of containers not using the off-dock warehouse minus those picked up immediately;
- Between the end of the flat rate ($\bar{t}$) and t_p: the remaining number of customers not using the off-dock warehouse, $\alpha(f^i(t)-f^i(t_p^i))$; and the customers rescheduling, $\alpha\bar{f}^i(t)$; and
- After t_p: the remaining containers of those customers rescheduling.

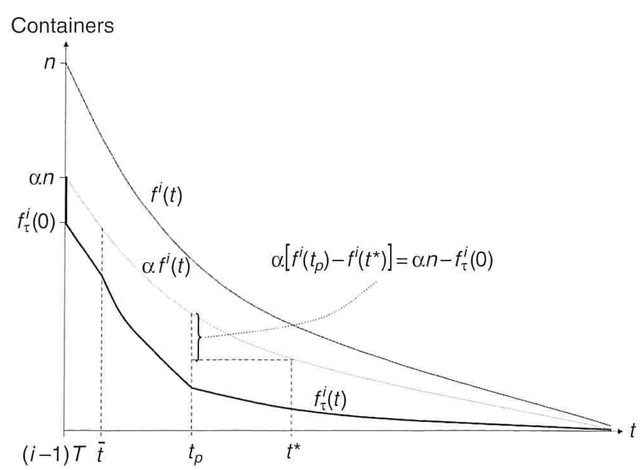

FIGURE 4 Cargo (from ith unloading) stored in terminal yard before (f) and after (f_τ) charging a tariff.

The after-tariff functional form is then

$$f_\tau^i(t)=\begin{cases}\alpha\left[f^i(t)-f^i(t_p^i)+f^i(t^{*i})\right] & \text{if } [i-1]T\le t\le \bar{t}^i\\ \alpha\left[f^i(t)-f^i(t_p^i)+\bar{f}^i(t)\right] & \text{if } \bar{t}^i< t\le t_p^i\\ \alpha\bar{f}^i(t) & \text{if } t>t_p^i\end{cases}\tag{12}$$

where

$\bar{t}^i = \bar{t} + [i-1]T,$
$t_p^i = t_p + [i-1]T,$ and
$t^{*i} = t^* + [i-1]T.$

The instantaneous number of containers being picked up is the derivative of Equation 12:

$$\frac{df_\tau^i(t)}{dt}=\begin{cases}\alpha\dfrac{df^i(t)}{dt} & \text{if } [i-1]T\le t\le \bar{t}^i\\ \alpha\left[\dfrac{df^i(t)}{dt}+\dfrac{d\bar{f}^i(t)}{dt}\right] & \text{if } \bar{t}^i< t\le t_p^i\\ \alpha\dfrac{d\bar{f}^i(t)}{dt} & \text{if } t>t_p^i\end{cases}\tag{13}$$

Cost Model for Yard Operations

The fixed cost is not quantified here because the maximization of profit is independent from the fixed terms. The variable cost of the yard operations is essentially the cost of rehandling containers when picking up. Kim and Kim (*18*) take the variable cost as proportional to the expected time of rehandling and this as proportional to the average number of rehandles per pickup. Kim (*20*) estimates that the number of rehandles per pickup is linear in the average height of stacks (number of containers divided by the number of ground slots) and thus linear in the number of containers in the yard.

But the storage variable cost is expected to soar when the cargo in the yard approaches its maximum capacity, and thus a linear function is no longer suitable (see Figure 5). This soaring cost near the maximum capacity is caused by the increased number of rehandlings and also additional handling costs (damaged containers, delays, etc.).

A cost function such that the variable part of it will be approximately linear for low occupations and rise rapidly when reaching Γ is to be chosen. An appropriate one is

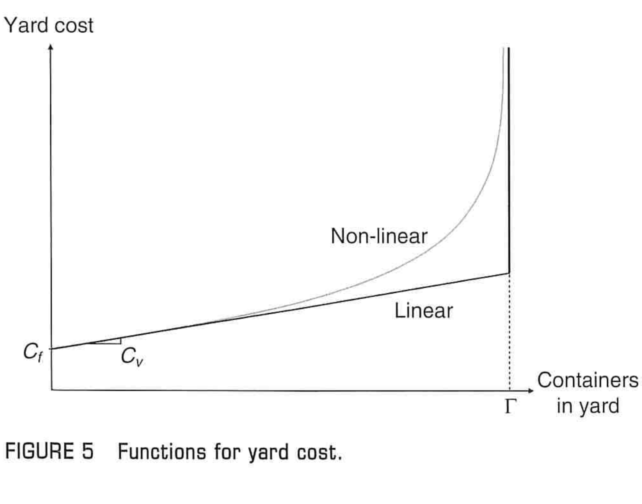

FIGURE 5 Functions for yard cost.

$$C(t)=C_f+C_v\left[\sqrt{\left(\Gamma-\sum_{i=1}^{N}f_\tau^i(t)\right)}-\sqrt{\Gamma}\right]\tag{14}$$

where C_f and C_v are fixed and variable storage costs, respectively. For low occupations, Equation 14 approximates through a linear Taylor series to

$$C(t)\approx C_f+C_v\frac{\left(\sqrt{\Gamma}\right)^3}{2}\sum_{i=1}^{N}f_\tau^i(t)\tag{15}$$

And now C_v can be calibrated with the formulas in Kim and Kim (*18*) and Kim (*20*). The total cost is

$$C(a,b,\bar{t})=C_f+C_v\int_0^\infty\left[\sqrt{\left(\Gamma-\sum_{i=1}^{N}f_\tau^i(t;a,b,\bar{t})\right)}-\sqrt{\Gamma}\right]dt\tag{16}$$

Revenues of Terminal Operator and Objective Function

The first source of revenue is the price for terminal operations. All containers shipped to the terminal are charged, so this stream accounts for $N-P$ times the volume of each unloading. Terminal costs (excluding yard operations) are assumed to be linear in the number of containers; they are not affected by congestion. Denoting the variable cost (constant and equal to the marginal cost) by C_T, the profit for the terminal operations is

$$D(a,b,\bar{t})=(P-C_T)(\alpha nN)=nN(P-C_T)\alpha(a,b,\bar{t})\tag{17}$$

Collecting the yard tariff is a second source of revenue. Because each T^i equals T^1 (all unloadings and delivery distributions are analogous to the first one) and the instantaneous number of containers leaving the yard is minus the derivative of the after-tariff distribution, the tariff revenue, R, amounts to

$$\begin{aligned}R(a,b,\bar{t})&=\sum_{i=1}^{N}R^i(a,b,\bar{t})=NR^1(a,b,\bar{t})\\&=N\int_0^\infty-\frac{df_\tau^1(t;a,b,\bar{t})}{dt}\tau(t;a,b,\bar{t})dt\\&=nN\alpha(a,b,\bar{t})\left\{\begin{matrix}a+e^{-\beta\bar{t}}\left[\dfrac{b}{\beta}+\left(a+\dfrac{b}{2\beta}\right)e^{\frac{-\beta c_0}{b-c_1}}\right]\\-e^{-\beta\cdot t_p(a,b,\bar{t})}\left[a+b\left(\dfrac{1}{\beta}+t_p(a,b,\bar{t})-\bar{t}\right)\right]\end{matrix}\right\}\end{aligned}\tag{18}$$

Finally, the objective function (profit minus fixed costs for the terminal operator) can now be easily obtained:

$$\Pi'(a,b,\bar{t})=D(a,b,\bar{t})+R(a,b,\bar{t})-C(a,b,\bar{t})\tag{19}$$

the maximization program being

$$\max_{a,b,\bar{t}}\Pi'(a,b,\bar{t})\tag{20}$$

which must be solved using numerical methods.

TABLE 2 Optimal Yard Tariff and Results for Numerical Example

Optimal Price Schedule			Results		
a (€)	b (€/day)	$\bar{t}$ (days)	Π'(€)	α (%)	t_p (days)
10.4	8.7	0	12,160	65.6	5.3

NUMERICAL CASE STUDY

Baseline Scenario

The authors applied their model to the study of a numerical example with the following parameters: $N = 5$ unloads, $n = 180$ containers/unload, $T = 2$ days, $\beta = ⅙$/day, $C_v = 10$ €/container/day, $\Gamma = 1.2nN$ containers, $c_0 = 30$ €/container, $c_1 = 5$ €/container/day, $P = 95$ €/container, $C_T = 75$ €/container. Table 2 shows the optimal values of the yard tariff (after a numerical optimization of the objective function), and Figure 6 shows the surface of the objective function. Note that fixed costs are not included.

The optimal $\bar{t}$ is zero, not only for the authors' specific parameters but also fairly consistently in parameters for other studies, as obtained in studies by Kim and Kim (*18*). However, the fixed part of the tariff (a) is found to be significantly greater than zero, contrary to the usual practice in most container terminals (see the introduction).

The composition of the profit, depicted in Figure 6, shows how costs and revenues behave when tariff parameters, a and b, change with only the optimal $\bar{t}$ (= 0) used.

When rates are low, costs soar (the less charged for yard storage, the more congested it becomes) and terminal handling profit increases (unsurprisingly, since it is proportional to the terminal demand). The effect is reversed when a and b increase.

Yard tariff revenue, similar to yard cost, grows inversely with the tariff parameters; there is a trade-off between collecting more money per container and attracting more containers.

Sensitivity Analysis

To study how a terminal operator should respond to changes in the characteristics of the problem, a sensitivity analysis is developed. Table 3 shows how the optimal values in alternative scenarios differ from the previous baseline example when, other things being equal, one of the basic model parameters is modified. The optimal flat-rate duration is always zero and thus not reported in Table 3.

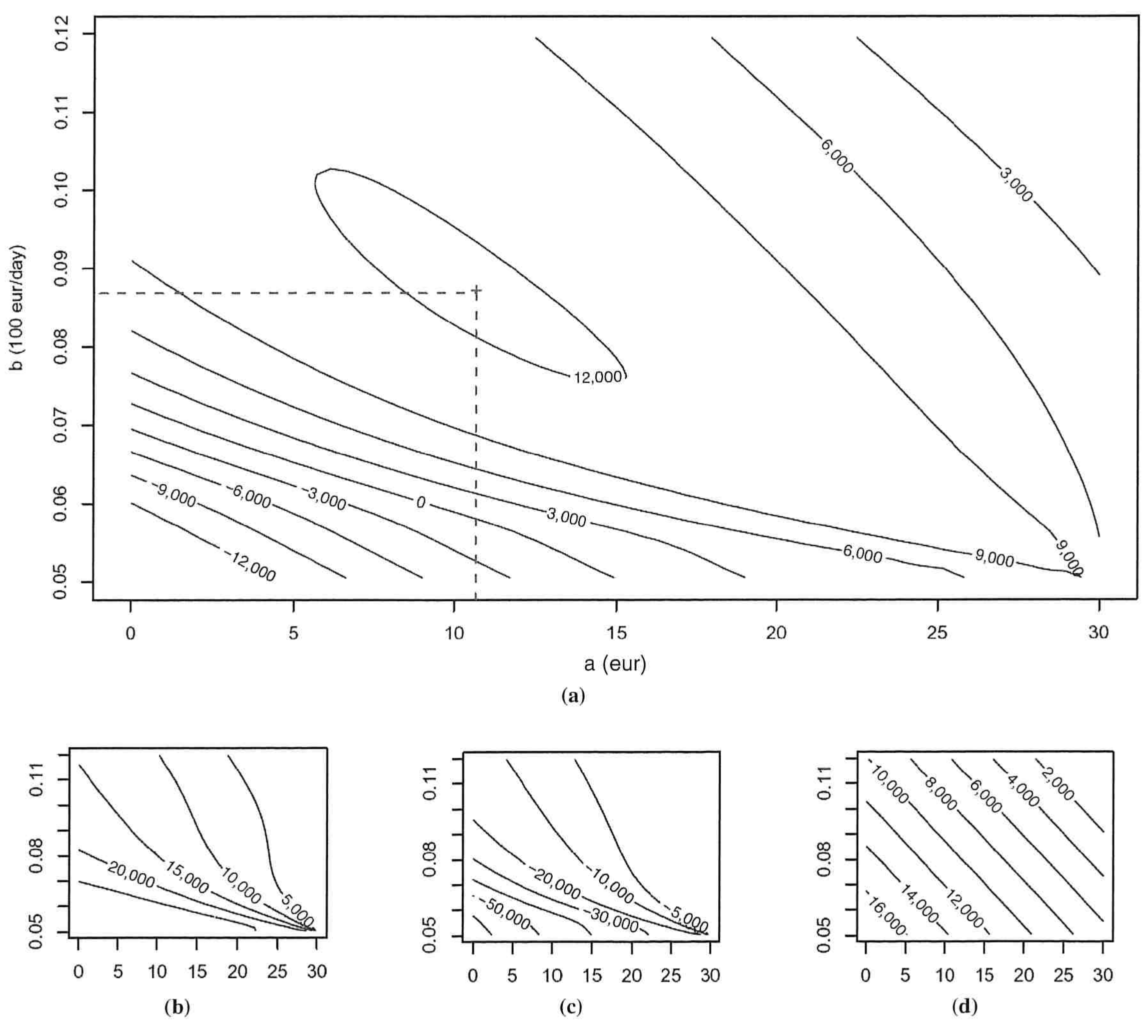

FIGURE 6 (*a*) Profit minus fixed costs and (*b–d*) its decomposition: (*b*) yard tariff revenue, (*c*) total yard variable cost, and (*d*) terminal handling profit.

TABLE 3 Percent Deviation with Respect to Base Scenario ($T_0 = 2$, $\beta_0 = 1/6$, $C_{v0} = 10$, $\Gamma_0 = 1.2nN$)

Scenario	a	b	Profit	α	t_p
$T = T_0/2$	−5.7	6.4	−0.8	−4.4	−10.4
$T = 1.5T_0$	0.0	−1.6	1.2	1.3	3.8
$1/\beta = 0.66/\beta_0$	−36.3	22.6	19.7	−12.9	−22.2
$1/\beta = 1.33/\beta_0$	47.5	−16.1	−14.1	5.6	20.3
$C_v = C_{v0}/2$	47.5	−38.8	69.2	24.7	740.0
$\Gamma = 0.6\,\Gamma_0$	18.1	−1.6	−3.4	−1.7	−6.1

NOTE: T = time span; β = rate of delivery; $1/\beta$ = mean delivery time; C_v = variable storage costs; Γ = temporary storage yard container capacity.

The inter-arrival time (T) has little impact on profitability (in this base scenario, the terminal yard operates with low congestion) but is in the expected direction; the more spanned vessel arrivals are, the lower costs applied by the yard. Delivery time from which customers decide to store off-dock (t_p) also reacts as expected; when T is reduced, customers pick up earlier, and when T is increased, customers pick up later.

The rate of delivery (β), with the mean of delivery times being its inverse, appears to be a key driver of the model. With a lower mean (that is, customers delivering earlier), the terminal slashes the fixed part of the tariff (a) increases the variable part (b) obtains more profit with both the relative demand (α) and threshold time (t_p) sharply reduced (as the terminal avoids congestion in the yard). An increasing mean has opposite effects.

If operational costs in the yard were to be drastically cut (by half in the alternative scenario, caused by mechanization or other sources of productivity), profit would soar because captured demand would be close to the pre-tariff level, and virtually no customers would be using off-dock warehousing.

Reducing the yard capacity (Γ), a sensible goal given the current pressure for saving terminal space, would have a very small effect on profitability. A terminal operator should then increase the fixed part of the tariff, allowing reduction of yard occupation (by slightly lessening the demand and stimulating early pickup) while maintaining similar revenues.

The demand captured by the terminal is driven mostly by the variable yard tariff, b. The higher b is, the lower demand becomes—except if the change in b is parallel to an opposite drastic change in a.

CONCLUSIONS AND FURTHER RESEARCH

Pricing schemes for inbound container yards were studied here. The model built incorporates the reactions of the customers in two ways: a direct reduction of demand caused by the introduction of a tariff and an indirect effect in the storage yard occupation because of migration to off-dock warehouses. The optimal tariff was, through numerical analysis, found to consist of a fixed part higher than zero and a variable part, with no period of flat rate.

General pricing guidelines for terminal operators were also obtained. The storage price per unit of time shall be increased when vessel inter-arrival time or the rate of delivery are lower. If yard costs are to be cut, the storage price per container is reduced proportionally. The fixed part of the tariff is increased when a reduction in yard cost or capacity occurs or when the delivery rate increases.

Demand behavior (responding to the yard tariff) could be inspected in greater depth, with particular attention given to the possibility that the demand from customers with different delivery rates may be differently affected.

As shown previously, the model is very sensitive to the delivery rate. Closer attention could be paid to delivery distribution by analyzing more flexible options.

Finally, the model developed here does not include some important aspects affecting demand, such as functionality of the entire network. A particularly interesting line of further research to accommodate such aspects could be the inclusion of stochastic analysis, especially regarding vessel arrivals or network delays.

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The Intermodal Freight Terminal Design and Operations Committee peer-reviewed this paper.

Reducing Train Turn Times with Double Cycling in New Terminal Designs

Anne Goodchild, J. G. McCall, John Zumerchik, and Jack Lanigan, Sr.

North American rail terminals need productivity improvements to handle increasing rail volumes and improve terminal performance. This paper examines the benefits of double cycling in wide-span gantry terminals that use automated transfer management systems. The authors demonstrate that the use of double cycling rather than the currently practiced single cycling in these terminals can reduce the number of cycles required to turn a train by almost 50% in most cases and reduce train turn time by almost 40%. This change can provide significant productivity improvements in rail terminals, increasing both efficiency and competitiveness.

As the North American economy and international trade volumes significantly expanded in the 1980s, the introduction of double-stack service—beginning with the Southern Pacific Railroad in 1981 (*1*)—effectively doubled rail capacity where there were sufficient height clearances. Where there were not sufficient height clearances, the railroads often invested in infrastructure to create the necessary double-stack clearances. This increase in capacity coupled with an increase in main line average speeds (*2*), and double and triple tracking in strategic corridors, put a strain on capacity at the terminals. The Class I railroads nevertheless have continued to make rail (intermodal and carload) more competitive: from 2002 to 2007, rail productivity (rail revenue ton-miles per employee) increased by 11% (*3*).

Terminals in the late 1970s and early 1980s introduced many major innovations that allowed the industry to efficiently grow. These included the two-for-one ramp design (where loads are prestaged on one side while unloading occurs on the other side), center-row parking, chassis racks, and continuous duty-cycle overhead and side-lift cranes (*1*). However, a new wave of innovation is needed to ensure that intermodal rail shipping, which grew 4.9% annually from 2003 to 2008 (*4*), will not lag well behind trucking through the years 2020–2025 as forecast (*5–8*).

Although future rail productivity gains will be tougher to achieve, new and retrofitted intermodal terminals that transition away from wheeled operations (container on parked chassis) hold great promise. That is because of the major shortcomings of wheeled operations, foremost of which is the need for an ample chassis fleet to maximize chassis use (and the necessity of providing for their storage, stacking, tracking, and maintenance). A second shortcoming is the need to track and manage multiple truck scenarios (e.g., empty chassis drop off, container drop off and pick up, leaving empty after drop off, leaving bobtail after drop off, and chassis flips—the transfer of a container from a bad chassis). Third, wheeled operations require a fleet of yard tractors to shuttle chassis, with and without containers, to and from the ramp and remote storage area. Fourth, labor productivity suffers from the considerable amount of time drayage and yard tractor drivers spend connecting and disconnecting the chassis (also increasing equipment wear and tear). Fifth, the operation of the cranes and yard tractors must be synchronized, which is made more difficult by early- and late-arriving trains. Sixth, chassis fleets entail enormous repair costs and phantom damage claims problems. And last, high container volumes require significant real estate, especially with greater free container dwell time allowances.

Capacity constraints at rail intermodal terminals have triggered debate on the future direction of terminal designs and container handling technology. Expanding existing wheeled operations at conventional rail terminals poses difficult challenges. Many rail yards in cities such as Chicago, Illinois, were built in the 19th century, a boom time for the railroads. Usually sited on undeveloped land at the edge of urban areas, these rail yards were eventually engulfed by urban development. Most were of more squared proportions for railcar traffic, which was not ideal for a modern intermodal rail terminal. Modern terminals benefit from larger tracts and longer rail spurs so that typical 100-well-car trains do not have to be broken apart into two or three units in the yard. While general freight terminals use multiple spurs to permit the assembly of fewer railcars to form train blocks, intermodal trains serve a much more limited number of cities, often are dedicated to one destination, and benefit from longer ramps to minimize switching to build and break apart a train. Purchasing adjacent real estate to build longer ramps is often not feasible because of a lack of availability, community opposition, high cost, and the need for environmental remediation. Construction of highways over and adjacent to rail yards also limits redesign and expansion options.

As Class I railroads continue evaluating investments in infrastructure that will profitably expand capacity, there is a need to examine the feasibility of terminal designs that can expedite train and truck turn times while simultaneously reducing cost, congestion, and associated emissions of both criteria pollutants and greenhouse gases. Unfortunately, megaterminal designs can create a paradox between turning trains and turning trucks (i.e., optimizing train turn comes at the expense of truck turn or vice versa when cranes must choose between servicing the train or the trucks). The wide-span gantry (WSG) crane terminal operations that include an automated transfer management system (ATMS) have been designed to achieve this goal by focusing all terminal activity under the cranes and offering immediate container selection for both crane operators and motor carriers (*9*). To determine the feasibility of turning trains even more

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quickly, this study examines the benefits of double cycling, which is a central design element of the ATMS terminal.

LITERATURE REVIEW

To address growing highway congestion, several studies have evaluated the feasibility of diverting more roadway traffic to the railways (*5, 10, 11*). These studies identify the high cost of constructing and operating rail intermodal terminals, drayage costs, and the drayage distance from the origin–destination (O-D) pair as major impediments to the growth in rail intermodal operations. Rail intermodal operations move a significant fraction of international freight but only a very small fraction of domestic freight. The studies by Bryan et al. (*10*) and Casgar et al. (*11*) recommend diverting more domestic traffic to circus loading (ramps with bridge plates) chassis or truck–chassis for shorter intermodal O-D pairs. But this approach is not as energy efficient (compared with double-stack service) and would slow the progress of container economies of density: the greater the density along a corridor, the easier and more profitable it is to provide more frequent service. With sufficient density, many more corridors can reach returns that match the scope and scale equivalent to that of the Los Angeles, California–to–Chicago route, where intermodal operations with high-capacity, high-frequency trains are competitive with truck service. Many corridors still need to grow the volume to support double-stack service as the ongoing transition from trailer service proceeds. For example, the BNSF Railway—the largest intermodal rail carrier in the world—has gone from a 1998 traffic mix of 62% containers/38% trailers to a 2008 rate of 92% containers/8% trailers, as intermodal volume grew by 48% (*12*).

Wiegmans et al. (*13*) considered the risk per reward of a new generation of rail terminals but did not define what technology this entails; moreover, application of such data to North America is problematic because the volume of rail freight is much lower in Europe, and the analysis included shunting yards as well as railroad and transmodal rail. Terminal analysis should distinguish between capital and operating costs. The reduction of operating costs is paramount because it generates positive cash flow, generates profits for future capital investment, and (unlike capital costs) cannot be depreciated.

Double-cycling crane operations have been researched in the context of marine terminals, with a focus on developing methods to determine the benefits of double-cycling quay crane operations on container ships (*14*). That work was extended to determine the effects of double cycling in container port landside operations in an effort to increase productivity and improve vessel turnaround time (*15*). The results show up to 20% reduction in crane cycles and nearly 10% improvement on operational time. The research presented in this paper follows the methods and formulations developed by Goodchild and Daganzo (*14*) to estimate and model the benefits of double-cycling gantry cranes in the intermodal rail terminal.

BACKGROUND CONVENTIONAL TERMINAL OPERATIONS

Intermodal rail terminals consist of three interactive operations: gate, transfer, and storage. Storage has primarily been a wheeled operation, but stacking between loading ramps or in remote storage yards has grown in prevalence as freight volumes have increased.

All conventional container terminals are variants of two types: (*a*) chassis fleets–chassis storage areas with areas for parked container–chassis storage, and (*b*) stacked storage terminals that use remote storage areas and the center row to store stacked containers. Generally, small-volume terminals use wheeled operations or parked storage exclusively, and higher-volume terminals use parked storage but also stack in center rows and remote storage yards after all parking spots are taken. The following are the basic inbound and outbound operational sequences for a train turn.

Inbound Trains

Before an inbound train's arrival at a ramp, the yard tractors transport and parallel park a sufficient number of empty chassis trackside to unload all the top containers. Once the inbound train arrives, the inter-box connectors (IBCs) are unlocked by the ground personnel. Top containers from the double-stack car are then unloaded by a trackside overhead crane to the parallel-parked chassis. As the inbound train is being unloaded, yard tractor drivers usually begin picking up and delivering the chassis or inbound container to a storage area in the terminal. Yard tractor trips continue until all top containers are delivered to the designated inbound storage area. Next, railroad personnel remove the IBCs from all top castings of the bottom container sitting in the bottom cell of the double-stack car as yard tractors bring a sufficient number of empty chassis trackside from the chassis storage area to unload all the bottom containers. Bottom containers from the double-stack car are unloaded by the crane and then picked up and delivered to an inbound storage area. After the inbound train is unloaded, it becomes an outbound train.

Outbound Trains

Containers for the outbound train are sorted into blocks according to destination. When outbound containers are delivered by truck carriers to the terminal, the driver is given instructions on where to park the chassis–outbound container (a specific block location) in the storage area. Containers are stored in blocks with containers for the same destination. After all the chassis–outbound containers have been delivered and parallel parked trackside in blocks, the overhead crane loads them into the bottom cells on the train. Yard tractors then remove the empty chassis from trackside as railroad personnel install the IBCs in all container corner castings. The train is ready to pull once all the top containers are loaded and all IBCs are locked. Although this system has worked well for low-volume terminals, wheeled operations become increasingly more problematic as volumes increase. For a comprehensive account of conventional terminal operations, see Boidapu et al. (*16*).

WSG Stack Terminal Operations

The WSG terminal design eliminates yard tractors and stores containers under the WSG.

There are alternative WSG stack terminal designs: single and team. The single WSG operation features cranes straddling rail tracks, container stacks, and truck lanes; the team operation features one cantilever WSG feeder team straddling the truck lane and stacks, with the other cantilever loading team (higher cantilever to overlap) straddling the rail tracks, a few container storage rows, and sometimes truck lanes as well. With all storage under the cranes, both designs reduce three operations (gate, storage, and transfer) to two (gate and transfer).

There are considerable labor, traffic, and air quality benefits in eliminating yard tractors shuttling containers to and from storage, but the trade-off is additional lifts. Typically transfers involve a minimum of two lifts, with a period of storage in the stacks. Often there will be additional dig or rehandle lifts to retrieve the desired buried container for loading onto a truck chassis or railcar. However, the greater number of cranes improves the feasibility of more direct transfers (live lifts), which are rare at conventional terminals and difficult to achieve in practice without a negative impact on crane and drayage productivity. Although there are several WSG terminals in Europe, the first in North America was the 2008 opening of the BNSF Seattle International Gateway Yard featuring WSGs spanning three train tracks, four rows of containers, and two truck lanes. A second WSG terminal opened in Memphis, Tennessee, in 2010, followed by the CSX Northwest Ohio Terminal in 2011.

FIGURE 2 Two-high ATMS positioned under WSG crane and perpendicular to loading tracks.

WSG In-Line (One-Way Traffic) ATMS Terminal Operations

An ATMS is in essence an active robotic parking stall—a minicrane—that can elevate, lower, store, and block and stage (position) containers without using an overhead crane or side-loading lift equipment so that a rail or port customer can be accommodated immediately (Figure 1). Designed to position and transfer a container between or among modes, ATMS sequences include chassis-to-ATMS-to-railcar for outbound freight, and railcar-to-ATMS-to-chassis for inbound freight. Aside from unlocking, removing, reinstalling, and locking IBCs, terminals with ATMS trackside eliminate all preparation for the accommodation of the inbound and outbound trains, permitting the immediate unloading and loading of containers when the train arrives at the terminal. Truck carriers transferring outbound containers automatically block and stage containers safely from the confines of their cab.

The ATMS would be positioned perpendicular or parallel to the tracks, depending on capacity needs. Without assistance from terminal staff, containers can be loaded or unloaded from the tractor driver's chassis to or from the ATMS. The multicell ATMS can be used to service very-high-volume ramps, with the tractors uploading containers to the ATMS bottom cell and the cranes loading the train from the ATMS top cell (Figure 2). After the crane transfers the top container, the ATMS automatically lifts the container from below. By including the ATMS trackside, the need for yard tractors is eliminated (*9*). The ATMS ensures that the crane operator never has to wait for the tractor driver and the tractor driver never has to wait for the crane. The ATMS simultaneously stores and stages containers for loading or unloading. This is critical because outbound and inbound containers need to be staged in ATMS bays adjacent to one another. This reduces empty movement distance; after an inbound container is unloaded from the train to the ATMS, the empty spreader moves just 10 ft to load the outbound container from the ATMS to the train.

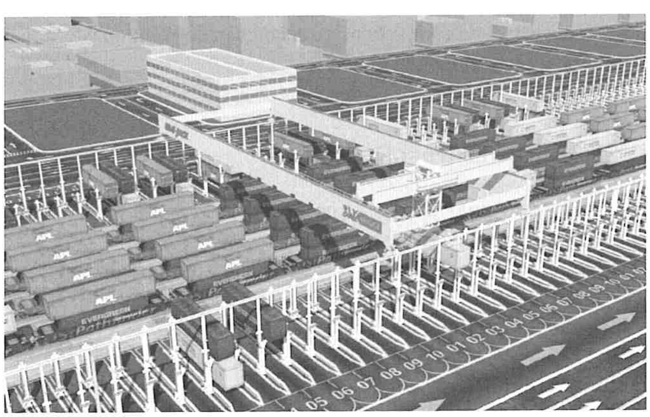

FIGURE 1 WSG in-line ATMS terminal. (Crane hovers over two-well car positions and 16 ATMS stations without traveling.)

DOUBLE CYCLING IN INTERMODAL RAIL TERMINALS

This paper's objective is to determine the potential to reduce train turn times for a WSG in-line ATMS terminal using double cycling to maximize productivity. The use of double cycling reduces the need to make empty returns by loading and unloading the train simultaneously. For example, after a container is removed from the train, the crane does not return to the train empty, but rather, carries a container to be loaded onto the train. Train turn time consists of three components: (*a*) changeover (refueling, maintenance, crew, and equipment); (*b*) disassembly or assembly into two or more units; and (*c*) unloading or loading by single or double cycling. Double cycling can occur in three variations:

1. From inbound to outbound for a single train,
2. Servicing two trains with inbound from one track and outbound from another, and
3. Servicing two trains with empty well cars brought to the ramp to work around a late-arriving train.

All three variations fulfill the double-cycling requirement of adjacent inbound and outbound well cars (the ATMS already has all inbound and outbound containers staged in sequence). For Variation 1, two single-cycling moves are first required to unload the top and bottom containers from the first well car. Thereafter, the synchronization of the loading and unloading phases begins, reducing traverse moves by 50% (and gantry travel by 75%, with one pass to unload or load the train compared with four passes for single cycling).

In the following sections, the number of cycles required to turn a train using double cycling is quantified and converted to an estimated time benefit for WSG terminals.

Double-Cycling Train Turn Analysis

This section examines the effects of double-cycling WSG crane operations with the ATMS terminal design. Double-cycling benefits are compared with single-cycle operations and quantified by the number of crane cycles. The methods of using the lower bound developed by Goodchild and Daganzo (*14*) are followed to determine the number of cycles. Where ω is the total number of cycles, Λ is the number of containers to be loaded, γ is the number of containers to be unloaded, and Π and Π' are defined as the loading and unloading permutations, respectively. For this paper the assumption is made that $\Pi = \Pi'$ and that all inbound and outbound trains are completely loaded and unloaded. Given this, the number of cycles can be defined as follows:

Single cycle:

$$\omega = \gamma + \Lambda \quad (1)$$

Double cycle:

$$\omega \geq \Lambda + u_{\Pi'(1)} = \gamma + l_{\Pi(1)} \quad (2)$$

This analysis assumes a 5,000-ft ramp and train and a train with 83 double-stack well cars. In the first case, all containers are assumed to be 40 ft; in the second, 30% are assumed to be 20 ft-containers (70% are 40-ft). Using Equations 1 and 2, the number of required cycles is determined and the results are compared and presented in Table 1.

In all cases, there is nearly a 50% decrease in the number of cycles required to turn around the train when using double cycling as compared with single cycling. The two-container stacks in the rail cars allow for a near optimal crane productivity with only two empty crane moves per 83 well cars when double cycling.

Train Turn Analysis Case Study

In this section, the number of estimated cycles from the previous section are used to estimate the time required to turn a train, based completely on cycle time, assuming any other factors involved in turn time remain constant and are independent of crane operations. The five different track scenarios presented here are examined. In each case, the time required is compared using both single- and double-cycle crane operations from the following:

1. Single track with 10-ft traverse length,
2. Single track with 40-ft traverse length,
3. Single track with 90-ft traverse length,
4. Two tracks with 10-ft and 25-ft traverse lengths, and
5. Two tracks with 40-ft and 55-ft traverse lengths.

Crane data are used for a typical rail-mounted gantry crane. The traverse speed has been given as a maximum value. In typical crane operations, the maximum speed is rarely reached because of safety and precision restraints. Traverse times may also vary with each lift, depending on the talent of the operator. The authors have assumed the average traverse speeds to be 70% of the maximum when traversing with an empty spreader and 30% of the maximum when loaded. In each case, the time has been estimated for one complete cycle. The use of the ATMS allows immediate load or unload when the crane operator is ready. Each cycle movement includes the traverse, hoisting, return traverse, and final hoisting activities. The hoisting distance will be constant and has been estimated at 20 ft. The gantry speed used in this analysis is 70% of the maximum speed specified by the manufacturer.

Double cycling has a significant impact on gantry time; Table 2 shows a large decrease in gantry time when double cycling is compared with single cycling. With single cycling, the crane must travel the length of the track four times (two times during unloading and two during loading). With double cycling, the loading and unloading phases are completed with one gantry down the length of the ramp. However, the cycle times increase because of slower traverse speeds when moving with a container (compared with 50% empty-spreader moves with single cycling). The results in Table 2 demonstrate that the reduction in gantry time and empty traverse moves exceeds the increase in cycle time, resulting in significantly reduced turn times with double cycling.

It was noted in the previous section that the benefits of double cycling produced nearly a 50% decrease in the number of cycles required to turn a train when compared with single cycling. Figure 3 shows the percent decrease in the estimated train turn time to be 38%–40%.

Although double cycling reduces the number of cycles, the time of each cycle is increased because the hoist and traverse speeds are reduced when a spreader carries a full container. With double cycling, the crane spreader is full for a larger percentage of the cycle. Because traverse speeds vary, the authors introduce a range of ±20% to the traverse speed to understand the impact on cycle time reductions. The results are shown with the error bars in Figure 3.

The benefit of double cycling improved as the number of containers was increased. When considering Figure 3, the percent benefit seems to inversely correlate with the traverse length. However, Figure 3 includes gantry travel time, which increases with traverse length. When the turn time is considered only as a function of the number of containers and gantry travel is excluded, the positive correlation is again seen between the benefit of double cycling and the number of containers.

The traverse length has a large effect on the crane cycle time; a longer traverse will result in a longer cycle time. Double cycling reduces the number of cycles by nearly 50%, a factor that becomes

TABLE 1 Train Turn Analysis

	166 40-ft Containers per Track			216 Containers per Track (30% 20-ft)		
	Single Track In- and Outbound Service	Two Tracks In- and Outbound Service	Two Tracks with Empty Outbound	Single Track In- and Outbound Service	Two Tracks In- and Outbound Service	Two Tracks with Empty Outbound
Single cycles	332	664	664	432	864	864
Double cycles	168	334	332	218	434	432
% decrease	49.4	49.7	50	49.5	49.8	50

TABLE 2 Double-Cycling Case Study Results

Track Setup	Single Cycle: No. of Cycles	Cycle Time[a] (s)	Gantry Time (min)	Projected Turn Time (min)	Double Cycle: No. of Cycles	Cycle Time[a] (s)	Gantry Time (min)	Projected Turn Time (min)	Percent Decrease
Single track, 10-ft traverse	432	41.4	60.5	359	218	54.9	15.1	215	40.1
Single track, 40-ft traverse	432	55.7	60.5	462	218	73.2	15.1	281	39.1
Single track, 90-ft traverse	432	79.7	60.5	634	218	103.7	15.1	391	38.2
Two tracks, 10- & 25-ft traverse	864	90	60.5	709	434	118.9	15.1	447	37.0
Two tracks, 40- & 55-ft traverse	864	118.6	60.5	914	434	155.5	15.1	580	36.5

[a]Cycle times are calculated from manufacturer specifications and estimated movement lengths. The crane speeds were derived from the following crane specifications: Hoisting speed: 30 m/min loaded and 60 m/min with empty spreader, trolley traverse speed up to 150 m/min, and gantry travel speed up to 240 m/min.

more important as the cycle time is increased with the traverse length. Because the gantry time remains constant for a given terminal (the length of the ramp), the relative impact of gantry time is less significant as the total train turn time is increased, either by increasing the number of cycles or traverse length.

WSG Terminal Benefits

A major goal of an in-line terminal is the seamless transfer of containers to reduce intermodal train turn times. Current train turn times are typically between 10 and 14 h. It is clear from the results in the previous two sections that double cycling with an ATMS can contribute to this goal while achieving lower crane maintenance costs (less wear and tear from 50% fewer moves). Considering the broader terminal benefits of a WSG terminal with an ATMS trackside, it can be seen that by unloading and loading trains faster, more loading tracks are available more of the time and fewer trains have to wait outside the terminal at sidings, providing the terminal operator greater flexibility to keep trains on schedule.

Intermodal operations center around the train schedule that connects the throughput of the yard to the network, and the faster and more reliably trains can be turned, the greater the capacity of the terminal. The ATMS WSG terminals reduce operating costs compared with conventional terminals by eliminating

- Chassis for wheeled storage, yard tractors, and drivers;
- Repair, maintenance, parts, service, and inventory costs for chassis and yard tractors;
- Staff buffer to service daily peak hours as well as low productivity man hours during off-peak hours; and
- Searchers trying to locate misparked containers.

The elimination of yard tractors, chassis fleets, and reductions in terminal staff will result in significant operating cost savings. For example, the annual operating cost for each yard tractor ($64,000 for a new yard tractor) operating 2,000 h is estimated at $32,000 (*17*). Adding a labor cost of $90,000 ($45/h), results in a $122,000 operating cost per yard tractor, or $9,150,000 annually for a fleet of 75 yard tractors. Significant operating cost savings will come from the elimination of the chassis fleet as well (maintenance and repair of chassis and chassis stackers, inspections, storage costs, and insurance).

In conjunction with other innovations, train turn times can be reduced further. Converting the benefit of immediate selection into actual train turn time savings is difficult to quantify. To understand some of the other train turn time savings, movement and event reductions should be considered; eliminating yard tractors from shuttling chassis to and from storage areas will eliminate an additional 432 movements and events (216-container train × 2), and replacing IBCs with side-box connectors will eliminate another 1,728 (864 × 2) movements and events. Table 3 summarizes all the operations involved in turning the 216-container train for a conventional wheeled terminal operation compared with the most efficient modern terminal (in-line WSG ATMS terminal using side-box connectors). Aside from a reduction in movements and events and the actual time to perform these movements and events, there also will be the elimination of coordination delays with cranes.

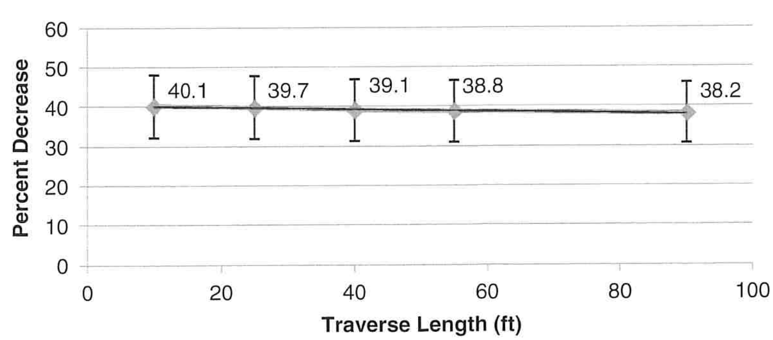

FIGURE 3 Percent decrease of estimated train turn time as function of traverse length in double cycling (number of containers is fixed at 216).

TABLE 3 Train Turning Operation Frequency in Conventional and ATMS Terminals

	Movements and Events (conventional)	Movements and Events (ATMS)
Unloading Phases		
Empty chassis from the storage area connected and driven trackside, disconnected and parked for loading	133	
IBCs disconnected, top container released	864	864
Spreader traverses empty to pick up top containers of double-stack car	133	[a]
Empty spreader lowered 10 ft to engage container	133	133
Engages corner castings, lifts container from double-stack car	133	133
Spreader traverses with container 25 ft	133	133
Spreader lowers container to chassis 17 ft	133	133
Gantry moves to next car to unload containers	83	83[3]
All loaded trackside chassis delivered to storage for local pickup	133	
All IBCs are removed from bottom containers	864	
Empty chassis from the storage area connected and driven trackside, disconnected and parked for loading	83	
Spreader traverses empty to pick up bottom container	83	[a]
Spreader lowered 10 ft to engage container	83	83
Spreader engages corner castings, lifts container	83	83
Spreader traverses with container 25 ft	83	83
Spreader lowers container to chassis 8 ft	83	83
Gantry moves to next car to unload containers	83	2[b]
All trackside containers–chassis delivered to storage for local pickup	83	
Loading Phases		
Outbound chassis–container connected at the storage area, driven trackside, disconnected for train loading	133	
Spreader traverses empty to pick up container from chassis	133	[a]
Spreader lowered to engage container from chassis	133	133
Spreader engages corner castings, lifts container	133	133
Spreader traverses with container 25 ft	133	133
Spreader lowers container to double-stack car 10 ft	133	133
Gantry moves to next car for loading containers	83	2[b]
IBCs inserted in bottom containers	864	
Spreader traverses empty to pick up container from chassis	83	[a]
Spreader lowered to engage container on chassis	83	83
Spreader engages corner castings, lifts container 17 ft	83	83
Spreader traverses with container 25 ft	83	83
Spreader lowers container to sit atop bottom container	83	83
Gantry moves to next car for loading containers	83	[a]
IBCs secure top to bottom containers	864	864
All empty chassis trackside driven to storage, disconnected and parked[b]	83	
Total	6,596	3,624

[a]No empty traversing and lower gantry number reflect double cycling for wide-span ATMS; one gantry pass (83) for loading and unloading versus 4 (83 × 4 = 216) for a conventional operation.
[b]The number of movements assumes that the conventional terminal parks chassis; if chassis are stacked or racked, 432 movements and events would be added.

Modern WSG crane-equipped terminals, with cranes capable of lifting a double stack, could provide "thruport" services in an inland port city such as Chicago or Memphis. A thruport is the equivalent of an airport for freight, in which multiple Class I railroads can dock and exchange freight, eliminating the current practice of trucks shuttling freight from one railroad's terminal to another railroad's terminal (*18*). Of the 13.98 million 20-ft equivalents that entered Chicago by rail in 2006 (*19*), anywhere from 30% to 50% is estimated to be interchange traffic (direct transfer from one train to another); the statistic is not tracked and is difficult to estimate because independent brokers generate the majority of rail intermodal sales. Building intermodal mega terminals with thruport services will be necessary for rail intermodal operations to efficiently evolve into a hub-and-spoke transportation network from the largely point-to-point model of today so that reliable and frequent intermodal service can be offered to an increasing number of O-D pairs. It also would help intermodal

networks better meet the needs of supply chain networks that were designed without taking intermodal operations into account (*3*).

Table 3 summarizes all the operations involved in turning the 216-container train for a conventional wheeled terminal operation compared with the most efficient modern terminal.

Immediate selection and double cycling that limits gantry travel gives terminal operators the ability to determine the train turn time desired and then equip the ramp with that number of cranes. Aside from the WSG ATMS terminal achieving a much faster train turn time for any given number of cranes, turn times can be further improved by adding cranes. But, adding cranes to the conventional terminal operation usually does not result in an appreciable improvement because of the greater congestion created and the difficulty in keeping operations synchronized as more equipment and labor is directed at turning the train.

In theory, a team WSG terminal could match the train turn time of the WSG ATMS terminal, but in reality this is unlikely for several reasons. Containers would need to be stacked so that train loading would not require additional rehandling and outbound stacked containers could be located as easily by the crane operator as the fixed positions of the ATMS. In addition, it would be difficult to replicate the ability of the ATMS to automatically communicate container identity to the gate, crane operator, shippers, consignees, dray firm, and driver the moment the container is set in the ATMS. Further, the additional rehandling lifts required because of stacking up to five containers high would necessitate more than twice as many cranes per ramp to achieve a similar train turn time.

CONCLUSION

The analysis shows that train turn times can be significantly improved with the use of double cycling in advanced terminals. Not only will this result in improved intermodal supply chain performance but also fuel savings, congestion mitigation, and air quality improvements.

Train turnaround time savings usually come in small increments or are too unreliable to allow train operators to adjust schedules to reflect these improvements. Once the terminal dwell time is reduced in a major way, reliably and predictably with double cycling, the dwell-time reduction can be captured, especially with 24–7 operations and improved routing protocols. This is critical because, for any given terminal, the faster trains are unloaded and loaded, the greater the capacity not only for the intermodal facility but the freight network as well. Likewise, the faster trains move in and out of terminals, the greater the number of trains that can be moved and the faster they can be moved. Because loading and unloading time at the origin and destination consumes a far greater share of the intermodal transit time as distance is shorter, reducing train turn time in concert with the efficiencies of double stack for the line-haul is the most effective means of achieving truck competitive service for shorter distances.

The results presented in this paper point to several future research initiatives. Future work will examine the impacts of emissions and energy and fuel consumption resulting from the use of double-cycling WSG cranes as well as the larger network impacts (for example, number of trains and the sensitivity of WSG cranes to train delays).

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Pacific Highway Commercial Vehicle Operations

Border Policy and Logistical Efficiency in a Regional Context

Matthew Klein and Anne Goodchild

Activities of commercial vehicles just before or just following international border crossings are not well understood. Logistical responses to border crossings are believed to increase miles traveled empty, total travel times, and total vehicle emissions. Analysis of observational data and surveys taken by commercial carriers at the Cascade Gateway border crossings (between Whatcom County, Washington, in the United States and lower British Columbia in Canada) improves understanding of how the border and associated policies and regulations affect logistics operations, both in manner and in scope. Findings suggest that the border creates logistical incentives for trucks to deadhead (cross the border without carrying goods as part of a cross-border round-trip journey) and to make staging stops near the border for border-related transloading. The Free and Secure Trade program, as observed in the Cascade Gateway region, unintentionally amplifies the existing negative logistical incentives created by the border.

Anecdotal evidence suggests that the border creates logistical inefficiencies, increasing truck miles traveled, empty truck travel, and fuel emissions. Near-border trucking logistics refers not to delays caused by queuing at the border but to routing, scheduling, stopping, and transferring that would not exist without the presence of the border. Current near-border operations practice is not well understood by the research community, but anecdotal evidence suggests that significant logistical inefficiencies are created by the border because of differences in size and weight restrictions, corporate structures, driver work rules, private-sector business models, international trade regulations, and communication mechanisms of the adjoining countries.

This paper has two objectives: to describe logistics practices near the U.S.–Canada border at Blaine, Washington, as uncovered through recent surveys of border crossers, and to examine the use and impacts of the Free and Secure Trade (FAST) program in the region. In meeting these objectives, the research reveals truck activity that would be unlikely to occur if the border were not present. For reasons consistent with private-sector incentives, the border creates stops and empty trips. The research also reveals that FAST is underused in the Cascade Gateway region, that its use is dominated by empty trucks, and that the program provides additional incentive to carry out logistical activities that result in increase in stops, vehicle miles traveled, and emissions.

This research was enabled by a data collection effort carried out in June and July 2009 on near-border operations for commercial vehicles at the Pacific Highway crossing between British Columbia, Canada, and Washington State (see Figure 1). To address the first objective of describing near-border logistics practices in the Cascade Gateway region, this paper answers the following questions: what is inefficient near-border activity, to what extent do these inefficiencies exist, and how are they associated with specific border policies? While the logistical activities undertaken may be consistent with carriers' incentives, inefficiencies refer to regional inefficiencies such as additional stops, extra vehicle miles, and increased emissions. To address the second objective of examining FAST in the regional context, this paper answers the question of whether there is evidence that the program provides incentives for less inefficient operations at Pacific Highway by promoting quick and predictable crossing times for empty trucks.

Motivating this analysis are the high number of empty trucks observed crossing the border and the low use rates of FAST. The data analyzed here represent not only a specific region but a specific time frame. Therefore, all analysis must be considered in the context of the temporal and geographic attributes of the regional trade during the study period. As Goodchild et al. observed, the commodity mix of cross-border trade in the Cascade Gateway region is quite different than that for trade along the eastern portion of the U.S.–Canada border. A comparison of the Cascade Gateway region with the Detroit, Michigan–Windsor, Ontario, Gateway shows that the Detroit–Windsor Gateway is dominated by manufactured goods that cross in a time-sensitive business environment, while the Cascade Gateway region sees high traffic in relatively less time-sensitive wood, paper, and plastics (*1*).

The data also represent a period of time during which the Pacific Highway border saw a significant trade imbalance. Looking at all modes of transportation, in 2009, U.S. imports from Canada were valued at almost \$225 billion (U.S. dollars), while U.S. exports to Canada were valued at just over \$200 billion. While there is some seasonal variation, values for June 2009 (when most of these data were collected) demonstrate this same relationship, with just over \$18 billion in southbound trade and almost \$17 billion in northbound trade. For Pacific Highway border trade by truck, the imbalance is even more pronounced: during June 2009, northbound truck trade was valued at \$342 million and southbound was valued at \$700 million (*2*).

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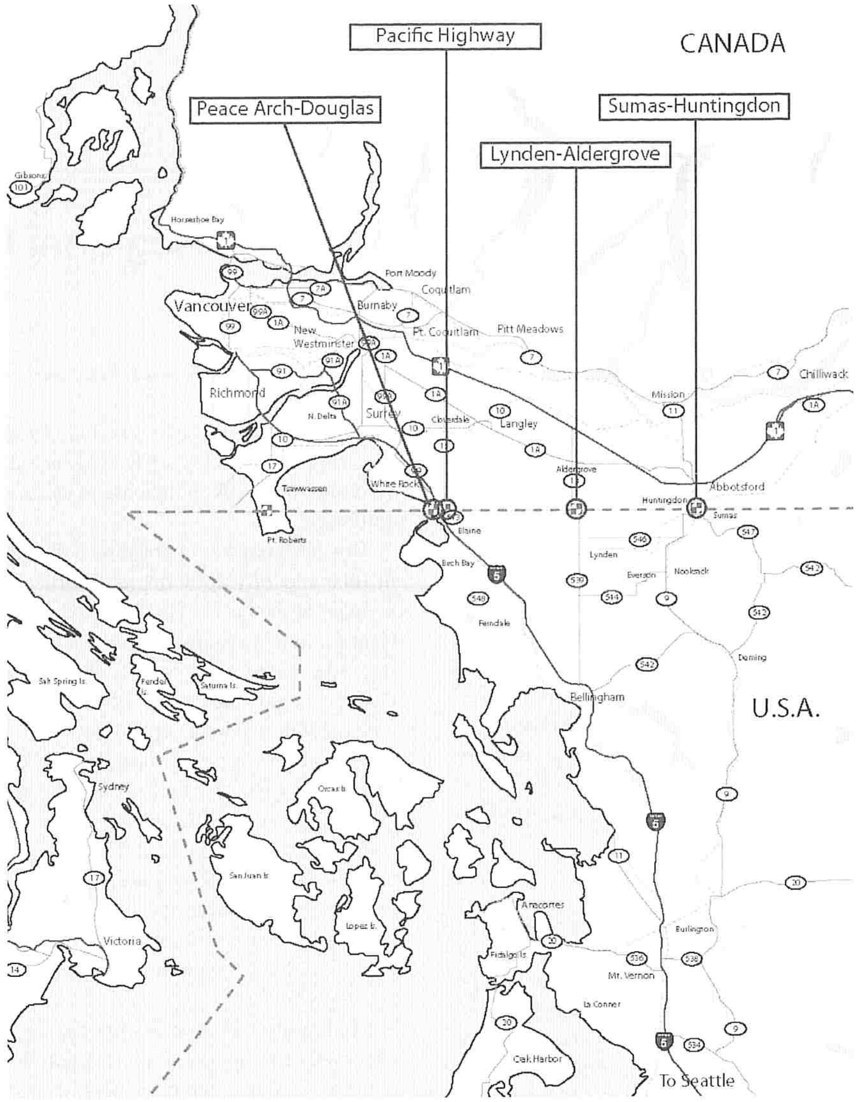

FIGURE 1 Regional map identifying the study location at Pacific Highway (courtesy of International Mobility and Trade Corridor Project).

LITERATURE REVIEW

Unnecessary Stops

One logistical and environmental border cost considered is the number of unnecessary stops made at near-border facilities. While these stops may be rational for individual transportation providers, their description as inefficient is based on the logic that the stops would not have occurred if the border had not been present. Before the 1980s, because of higher transportation rates in Canada, small businesses often avoided using Canadian carriers by privately transporting goods across the border to interline (transport goods by two or more transportation lines) with U.S. carriers, a practice that both encouraged U.S. firms to locate closer to the border and caused Canadian carriers to drastically reduce their rates (*3*).

Jones argues that regulations involving foreign truck entry distort markets not only by affecting the number of trucks entering the country but the freight infrastructure along the border as well (*3*). The United States, deregulating its trucking sector with the Motor Carrier Act of 1980, greatly reduced entry and exit barriers for trucks. Subsequently the number of trucking establishments (e.g., terminals, transportation brokers, and warehouses) along the border decreased. However, when the Canadian government similarly eased entry and exit barriers in 1987 with the Motor Vehicle Transportation Act, the number of near-border trucking establishments increased. As Jones found, the commercial zones around the U.S.–Canada border crossings saw a 47% increase from 1977 to 1991 in the number of businesses categorized by Standard Industrial Classification code 421 (trucking and courier services, except air). Examining this trend, Jones found that from 1977 to 1986, the rate of these establishments remained fairly constant at an average of 0.15 per million dollars of trade. After 1987, when Canada began allowing previously limited numbers of U.S. trucks to cross more freely into Canada, the rate of brokers per value of trade rose substantially until 1991, averaging around 0.195 establishments per million dollars of trade. The increased competition and cabotage laws accompanying deregulation created incentives for truckers to include an empty cross-border leg as part of an international round trip. This caused an increase in near-border trucking facilities to help truckers consolidate loads and reduce deadheaded (empty return trip) miles (*3*).

FAST Program

FAST is a joint U.S.–Canada initiative allowing expedited border crossing for low-risk shipments for which the driver, carrier, and shipper have all been vetted by the respective border security agencies. At certain major border crossings, including Pacific Highway, FAST has dedicated lanes that greatly improve border crossing time and predictability over the general purpose lanes. However, FAST is underused at the Pacific Highway border. Customs and Border Protection data estimate that in 2008 only 8% of eligible U.S.-bound shipments at the Pacific Highway border crossing used FAST, compared with 44% at the Detroit–Windsor crossing, 31% at Port Huron, Michigan–Sarnia, Canada, and 23% at Buffalo, New York–Fort Erie, Canada. Of the 16 border crossings for which U.S.-bound FAST data were available, only two crossings had lower percentages of FAST use: Massena, New York, and Sweetgrass, Montana, neither of which has dedicated FAST lanes (*4*). A 2008 Border Policy Research Institute policy brief estimated that in October 2007, less than 5% of trucks at Pacific Highway used FAST, compared with 23% of trucks at the Buffalo–Fort Erie border (*5*). The institute pointed out the dominant use of FAST by empty trucks at Pacific Highway (73% of southbound trucks and 41% of northbound trucks): "The large number of empty trucks crossing the [Pacific Highway] border could be linked either to market-driven commodity flows or to policy-based flaws in the design of freight-inspection processes." (*5*) This analysis suggests that one explanation could be related to FAST requirements. The shipper, carrier, and driver must all be FAST-approved to use the FAST lane; however, carriers and drivers are often more strongly associated with each other and can more easily implement FAST requirements; these factors create an incentive for only carrier and driver to enroll in FAST (*6*). Furthermore, there is a known lack of FAST-approved shippers (*7*).

Commodity also plays a role in FAST use rates. As Goodchild et al. have noted, FAST is underused at Pacific Highway when comparing border crossing use along the eastern portion of the U.S.–Canada border, where border crossings see higher levels of goods movement between factories on both sides of the border. Goodchild et al. noted that at the Pacific Highway border crossing, bulk and empty container–pallet trucks preferred the FAST lane, while manufacturing and food commodities were less likely to use the FAST lane (*1*). Arguably, FAST works poorly at borders such as Pacific Highway, where securing supply chains is difficult because of large amounts of agricultural and less-than-truckload shipments (*5*).

Examining how FAST provides incentives for trucks to cross empty can be understood by considering costs associated with variability and duration of border crossing delays. Taylor et al. calculated that in the years following September 11, 2001, uncertainty in border crossing times was estimated to be responsible for $1.99 billion per year in costs impacting manufacturers, and that the likely costs of delay and uncertainty constituted 1.58% of the total value of cross-border truck trade (*8*). In a study measuring the costs of border delays, consultants calculated that border delays cost the Canadian trucking industry between $231 million and $433 million in 2004 (*7*).

Globerman and Storer explain that these factors impact border crossing operations because longer waiting times impact costs such as fuel and hourly pay, and variability impacts inventory costs and an increased allotment for travel times (*9*). Examining variability at Pacific Highway, Goodchild et al. noted that goods movement at Pacific Highway are not as time sensitive as those that are in more time-intensive environments such as the Detroit–Windsor Gateway. Hence variability of crossing times at Pacific Highway is not a major concern, and building in extra buffer time is a common strategy to manage border service time variability (*10*). In their review of strategies to address border crossing time variability, although they discussed reduction of activities on cross-border trade, they did not investigate the strategy of deadheading through the FAST lane, possibly sacrificing the acquisition of a load for a backhaul (return) leg in exchange for the convenience of quickly and reliably crossing empty using the FAST lane.

Based on previous assessments that FAST is not well-suited for trade at Pacific Highway, this research describes near-border operations in the Cascade Gateway region and shows how FAST impacts this logistical environment. FAST was designed to assist in the movement of materials quickly and efficiently across borders, but at Pacific Highway the data indicate that FAST is heavily used to relocate empty trucks—and provides incentives to replace loaded truck trips in both directions with multiple truck trips that deadhead across the border in one direction.

In the Cascade Gateway, methods to more efficiently use the existing infrastructure have been discussed and, to some extent, explored. On some occasions, for example, the southbound FAST lane at Pacific Highway is opened to general traffic to ease congestion in the general purpose lanes when the FAST lane is underused. A congestion-based toll was studied by Roelofs and Springer, but they found that without adding an extra lane and booth such a solution was unlikely to be implemented or even go beyond the planning stages (*11*). There has also been some analysis of potential revisions to FAST to make it appeal to more shippers, thereby increasing use of the FAST infrastructure (*5*). While other solutions may have been discussed by individuals or small groups, no apparent incentive programs to encourage FAST participation have been implemented or studied.

DATA SOURCES

Observational and Survey Data Sets

Data made available through the cooperative efforts of a consortium including members from the University of Washington, the Border Policy Research Institute at Western Washington University, and the International Mobility and Trade Corridor Project sheds light on these inefficient operations. During June and July of 2009, observational data were collected by the consortium at the three commercial border crossings of the Cascade Gateway: Pacific Highway, Lynden, Washington–Aldergrove, British Columbia, and Sumas, Washington–Huntingdon, British Columbia. Data were collected in 2009 at Pacific Highway on Mondays through Thursdays during various hours between 9:00 a.m. and 9:00 p.m. on the days of June 15 through 18 and 22 through 25. Instructions to complete an Internet-based survey were distributed to all trucks observed ($n = 2,979$). Unless stated otherwise, all analysis referring to "observational data" is based on data collected at Pacific Highway, the busiest of the three border crossings and the only one with FAST infrastructure.

For the 2,979 trucks to which surveys were distributed, 215 unique survey responses were received, of which 211 were analytically useful. This data set is referred to as the survey data. The surveys themselves capture information for a single cross-border round trip. If a truck made more than one round-trip that day, the data collected account for only the first round trip. Because very few incidents of multiple single-day round trips were observed, analysis in these cases was limited to the first round trip.

Preliminary Data Analysis

Although the data do not reveal which trips were part of a same-day round trip and which were part of longer trips, it is possible to identify

trips that would be unlikely to have been part of a same-day round trip. Given the hours-of-service regulations of the U.S. Federal Motor Carrier Safety Administration (maximum 14 hours on duty, 11 hours driving time) (*12*) and the Canadian Council of Motor Transport Administrators (maximum 14 hours on duty, 13 hours driving time) (*13*), a cross-border driver would be expected to drive no more than 11 hours in a single day. Assuming a generous average travel speed of 65 mph (105 km/h) yields a maximum likely same-day distance of 715 miles (1151 km). Thus, for the observed data, distances are rounded down to assume that any leg of more than 350 miles (563 km) is not likely part of a same-day round trip, and the analysis focuses on such regional trips. Of the 3,914 observed trips for which distances were calculated, regional trips accounted for the majority of Cascade Gateway commercial traffic, with 74.9% of trucks traveling less than 350 miles from origin to destination. This trend has been observed in previous studies (*1*). Furthermore, of the 25.1% of trucks that traveled more than 350 miles, 23.6% were empty; of the 75.0% of regional trips, 37.9% were empty, indicating that regional trips may be of more interest in an efficiency analysis.

EVIDENCE OF INEFFICIENT NEAR-BORDER ACTIVITY

Border-Induced Stops

Anecdotal evidence and previous research by Jones suggest that goods may be staged near the border so that equipment or drivers can be exchanged before crossing (*3*). The concentration of near-border activity can be measured by examining the concentration of origins and destinations by distance from the border. To determine the extent of this concentration that can be plausibly attributed to the border, population is considered as a rough surrogate for economic demand, and the ratio of stops to population is examined to gauge a level at which stops could be attributed to the border. While alternative metrics for economic demand could be used, population data are sufficient to capture the order of magnitude effects that the border has on transportation activity. Facility type, as indicated on the survey, is also examined to determine the nature of the trips made.

Using ArcGIS (a software suite) and population data obtained from Esri, a provider of geographic information system software, Figure 2 shows a high concentration of cross-border truck destinations (obtained from the observational data) per capita near the border. Locations near the border generate several orders of magnitude more destinations per capita than other locations. The cities with the highest destination per capita ratio are Blaine, Washington (abutting the border at Pacific Highway), followed by Ferndale, Washington, just to the south of Blaine along the Interstate 5 corridor. This concentration of freight activity on the U.S. side of the border validates assumptions of a buildup of U.S. near-border freight facilities.

Examination of the facility type sheds further light on the phenomenon of near-border freight operations. Each trip must originate at the cargo's source and ultimately arrive at the receiver's business location. While some intermediate stops are made at warehousing and distribution center locations for cost and inventory efficiencies, these trips increase vehicle miles traveled and associated social costs (emissions, fuel consumption, noise pollution, and safety concerns).

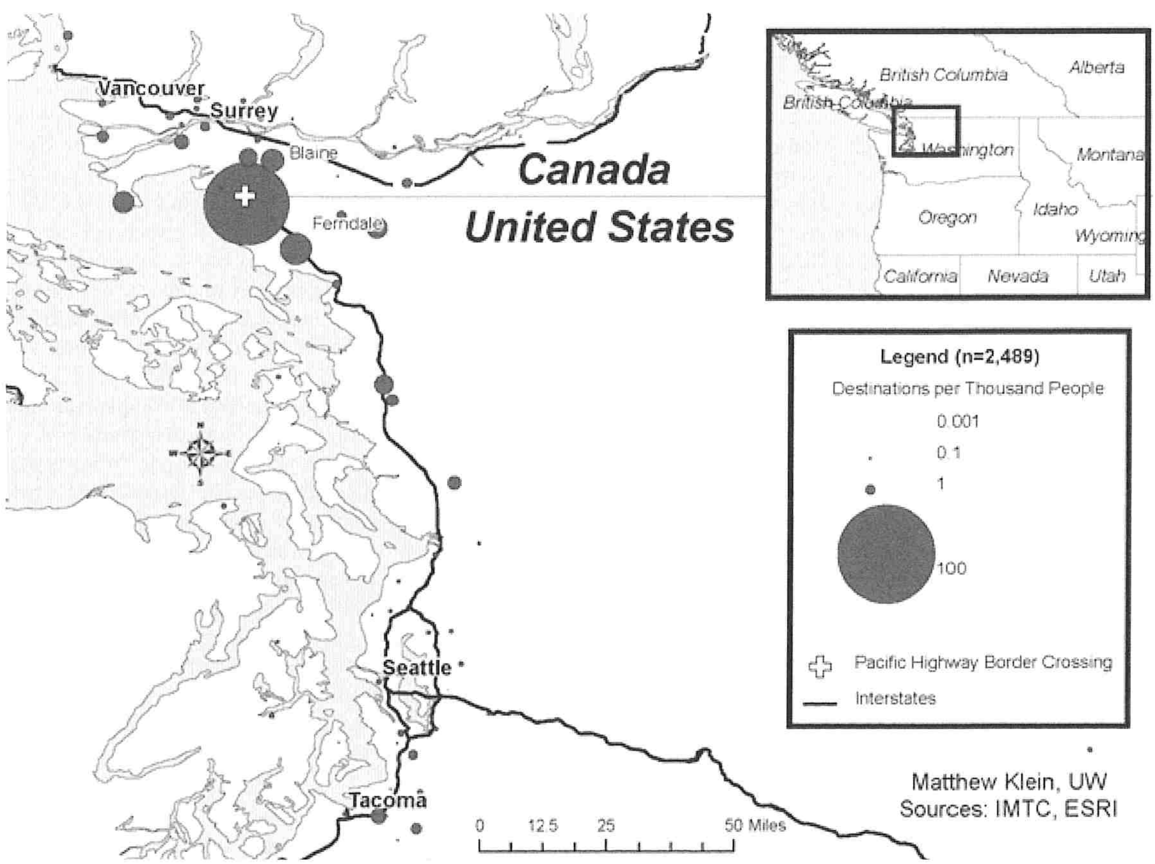

FIGURE 2 Destinations per capita.

Assuming that trips made to receivers' business locations, intermodal facilities, farms, raw materials locations, or distribution centers are classified as necessary stops and would occur whether the border existed or not, it is possible to bound the amount of unnecessary trips involving trucking company facilities.

Trips to a trucking company facility may demonstrate unnecessary trips generated by the border but may also be made for sorting or repackaging activities that reduce logistics costs. However, in a minimum stopping environment, trucks would travel only from shipper to receiver locations. For all northbound trips with goods, Figure 3 identifies at what type of facility each northbound trip originated and how far from the U.S. border that facility was located. Distances traveled were calculated by geocoding city and border locations (because of privacy concerns, city level was the highest level of resolution for which geographic information was available). Straight-line distances between city centers and the border were calculated to estimate distances traveled. This shows that, for northbound deliveries originating within 25 mi (40 km) of the border, the most common originating facility type is a trucking facility, with distribution centers as the second most common facility type. The data also indicate relatively few business locations near the border.

Border-Induced Empty Trips

The second metric is empty truck crossings. In the study period, 18% of northbound trips and 46% of southbound trips were empty. Though the regional trade imbalance at the time of the study suggests that southbound trucks were necessarily empty more often than northbound trucks, other factors impact empty trip patterns, such as specific commodity flow directions and equipment specialization. An analysis of individual commodity flows reveals which commodity types see more or less empty trip rates as necessitated by the levels of commodity trade (this assumes trucks serve only one commodity in both directions).

A less visible cause of empty truck trips, however, is the cost–benefit tradeoff, which determines whether or not a driver should return more quickly (and with less administrative cost) without cargo or search for cargo to make the return trip more profitable. The following sections demonstrate that increasing driving distance correlates with lower deadhead rates, and that FAST-lane traffic displays an exaggerated relationship between driving distance and deadhead rates.

FACTORS OF BORDER-RELATED EFFICIENCY

Factors that influence near-border operational inefficiency can be considered to be in one of two categories: market-related factors (such as commodity flow and trucking operations in a deregulated market) and policy-related factors (those not determined directly by market forces). In this paper, FAST is investigated as a policy-related factor influencing inefficient operations. Observations are discussed that can be made about the aggregate logistical behavior of shippers and carriers near the border without investigating the strategies, motivations, or decisions of specific fleets or logistics managers. While these motivations can provide insight into the effectiveness of policy changes, more detailed analysis of motivations informing business decisions in a complex market and regulatory environment is beyond the scope of this paper. Previous work from the same research group has considered fleet-specific responses to border crossing–time variability (*10*).

Market-Related Factors

Distance

This research demonstrates that generally the farther a truck travels from the border, the more likely it is to obtain a backhaul load to cover the costs of returning across the border. Figure 4 shows this relationship by examining backhaul rates from the survey data, excluding destinations with fewer than five trips. Locations such as Seattle and Tacoma, Washington, which are relatively distant from the border, see a higher rate of trucks that deliver to these locations and secure backhaul loads for the cross-border return trip.

Examining the observational data for all three border crossings reveals more nuanced trends in the relationship between distance and load rates. In this section, origin–destination distances are compared with trip-segment distances to and from the border alone. Figure 5 compares northbound origin–destination distances with northbound origin–border distances, revealing statistically significant relationships between load ratio and both distance measurements. Here northbound border–destination distances are excluded because of the short distances involved in driving between the border and Canadian destinations. The figure demonstrates that the further a truck travels, for both total origin–destination and border-to-destination distances, the more likely the truck is to obtain a load for its backhaul trip.

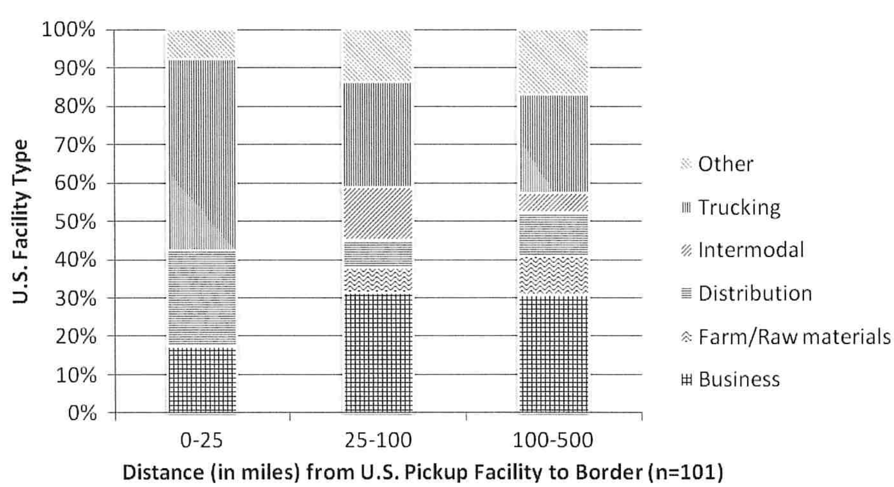

FIGURE 3 U.S. facility types by distance.

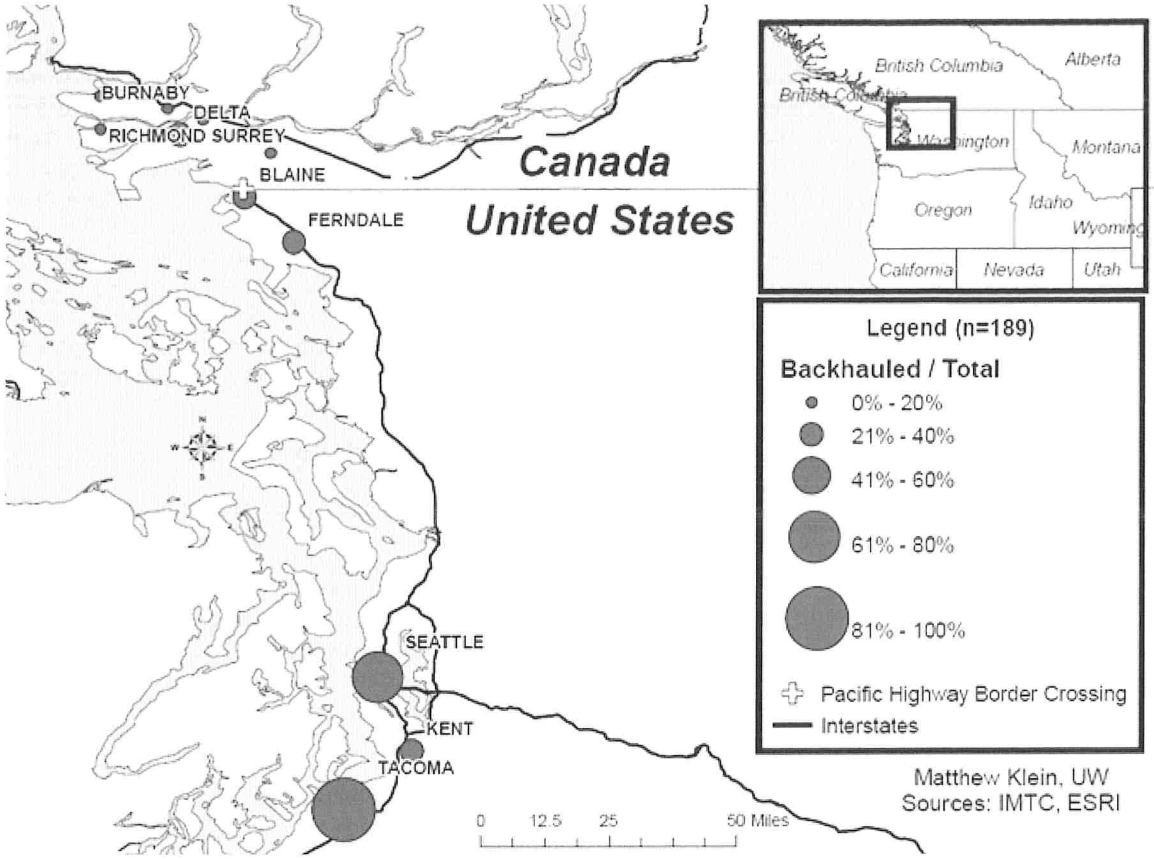

FIGURE 4 Backhaul ratios by delivery location.

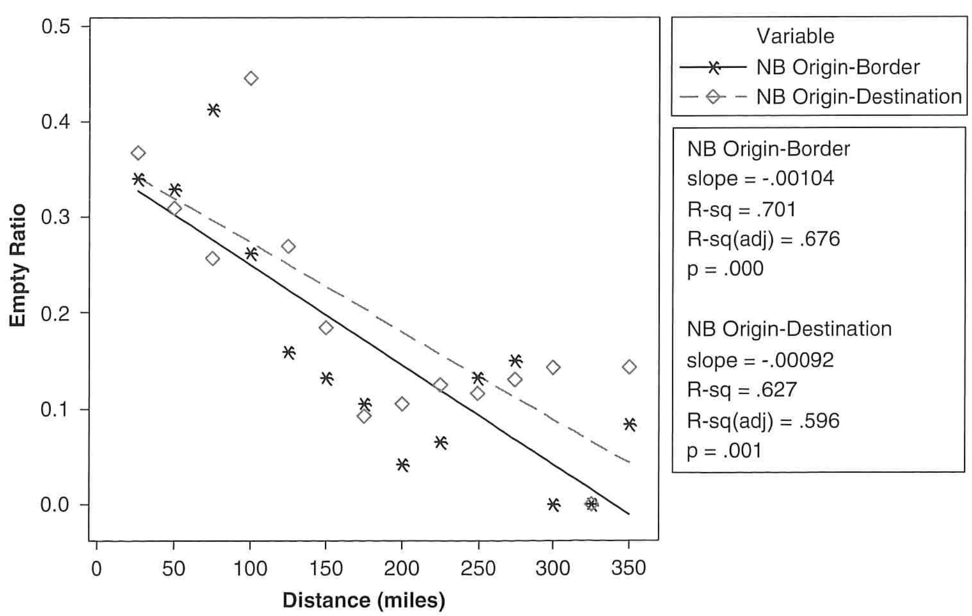

FIGURE 5 Northbound distances and load ratios.

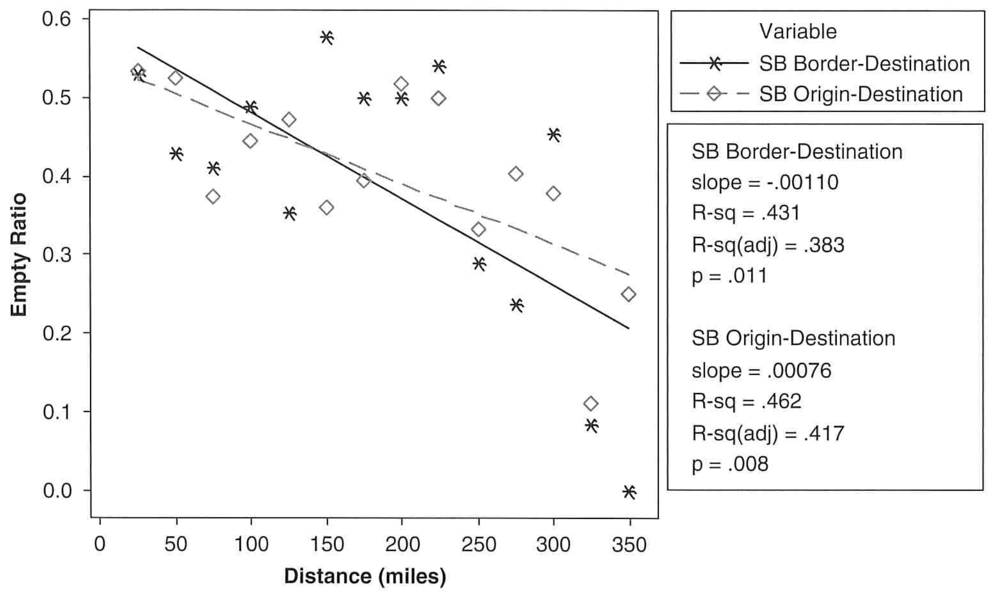

FIGURE 6 Southbound distances and load ratios (SB = southbound).

Figure 6 compares southbound origin–destination and border–destination distances, similarly excluding the southbound origin–border distances because of the short trip lengths involved. The results are similar to the northbound results in that there is a linear relationship, albeit less statistically significant than northbound regression results. Comparing these figures reveals that the origin–border and border–destination distances demonstrate empty rates that are steeper than origin–destination rates over distance traveled. Because the former calculations use border as the origin when measuring distance, the steeper slopes and higher near-border rates indicate that while there is a relationship where shorter trips see higher empty rates, the position of the border exaggerates this rate, resulting in more empty trips closer to the border.

Commodity

With the trade imbalance present at the time these data were observed, a certain amount of trucks must necessarily reposition empty across the border. In addition, equipment specifications and spatial and temporal distributions of demand reduce use rates. Examining trade imbalances for specific commodity types allows for the use of commodity-level backhaul rates to surmise what proportion of empty trucks are necessarily empty (because of commodity-specific trade imbalances) and how much excess capacity is crossing the border (although there may still be business-driven reasons for empty travel). This analysis is based on an assumption that equipment limitations only allow a truck to transport goods of a single commodity type in both directions. Chemical and farm goods often require specialized equipment such as refrigeration and specialized trailers; therefore, load matching may be limited within a commodity category.

Within this constraint, an analysis of the backhaul rates observed in the survey data determines how much potential for backhaul has or has not been used. For the six most common commodity categories observed in the survey data (reflecting summer trade), the following crossing patterns exist: manufactured goods, miscellaneous goods, and semifinished goods cross the border at near parity (less than 10% excess flow in either direction of travel); a majority of wood products move southbound; a majority of food and beverage goods move northbound; and the vast majority of farm goods move northbound.

Within each commodity category, the ideal rate of backhaul is calculated considering flow balance and the single commodity truck constraint. The "ideal" backhaul rate is based on an assumption that no trucks should be empty in the direction with more commodity movement. Assuming just enough trucks are used to meet this criteria, the ideal backhaul rate is the percentage of these trucks that would backhaul, given a load in the direction with less overall commodity movement.

Figure 7 compares these ideal backhaul rates with the actual backhaul rates observed in the survey data. Wood commodities see almost ideal backhaul rates, while movement of farm goods exhibits unused backhaul capacity. This could be explained by the need for specialized equipment to move certain types of farm goods and the time sensitivity of transporting perishable goods. Other commodities such as food and beverage, manufactured, miscellaneous, and semifinished goods use only between 30% and 50% of ideal backhaul capacity.

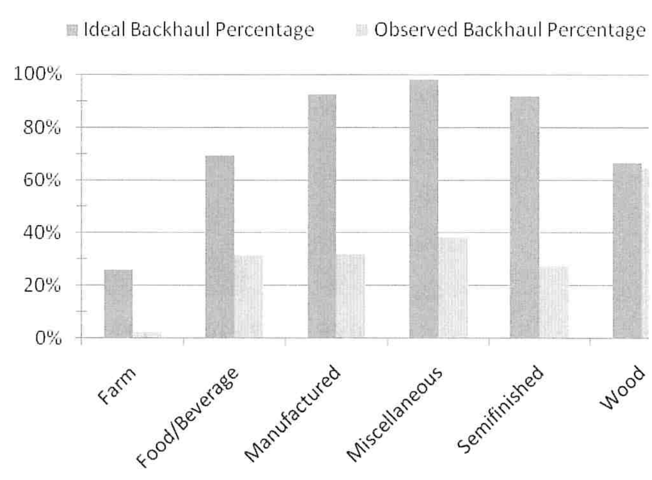

FIGURE 7 Ideal and observed backhaul rates by commodity.

FAST Impact

The 2009 observational data show that 14% of all trucks used the FAST lane at Pacific Highway crossing (25% southbound and 3% northbound). Of loaded trucks alone, only 6.5% in the observational data set used the FAST lane (1.2% northbound and 14% southbound). For each direction of travel, approximately two-thirds of all trucks using the FAST lane were empty.

The high rate of empty trucks using the FAST lane suggests that the FAST program at Pacific Highway may be providing an incentive to deadhead across the border rather than to seek out a backhaul load. Figure 8 identifies northbound trips by facility type of origin and the distance from the border for all trips that contained an empty southbound leg, categorizing trips by southbound lane choice. Of the southbound trucks that crossed empty only a short distance into the United States, having used the FAST lane as part of a trip where goods were moved northbound, the vast majority picked up goods at a trucking facility. This suggests FAST trucks (most of which are empty) are more likely to visit trucking facilities than are trucks using the general purpose lanes.

Another way to examine the operational incentives provided by FAST is to examine the relationship between distance and load status for trucks that use the FAST lane and those that do not. As before, the focus is on activities on the U.S. side of the border because of the longer distances involved, thus providing the ability to better differentiate the impact of distance on load status. Examining southbound Pacific Highway trips and aggregating trips into 50-mile bins, Figure 9 shows that while all empty trucks have a higher likelihood of crossing empty if destined for a facility near the border, those using FAST show a stronger sensitivity to the relationship between load status and distance. This suggests that the ability to cross the border quickly and reliably with the FAST lane creates further incentive to cross the border empty. For trucks in the standard lanes, each 100 mi (161 km) reduces the empty ratio by 10%; while for trucks using the FAST lanes, each 100 mi reduces the empty ratio by almost 30%.

CONCLUSIONS

Through analysis of unique survey data, this paper provides novel information about near-border logistical activities, the extent to which inefficiencies are present in these logistics, and the role that FAST and the border itself play in amplifying them.

Near-Border Operations

Describing near-border operations provides evidence of the clustering of logistical activities near the border. Using population as a surrogate for economic demand, near-border locations produce several orders of magnitude more demand for cross-border truck trips. The majority of near-border trucking activities occur at trucking facilities, indicating demand for staging activity created by the border.

The analysis also reveals a linear relationship between distance and load status. The farther into a country a truck travels to deliver goods, the more likely it is to obtain a backhaul load for the return journey. These backhaul rates differ by commodity type. Using survey data to infer what commodity an empty truck could be able to transport, trucks carrying commodities such as manufactured and miscellaneous goods did not use backhaul capacity as efficiently as trucks carrying wood products. Comparing border–destination segments with total origin–destination trip legs suggests that the border itself amplifies the linear relationship between distance and load status.

FAST Program

FAST is underused at the Pacific Highway border, considering that a third of the physical infrastructure is dedicated to trucks and, compared with other major northern borders, that the majority of users cross without a load. Addressing concerns of duration and predictability of border crossing times, empty trucks are able to use FAST to quickly deadhead across the border. In terms of the metrics

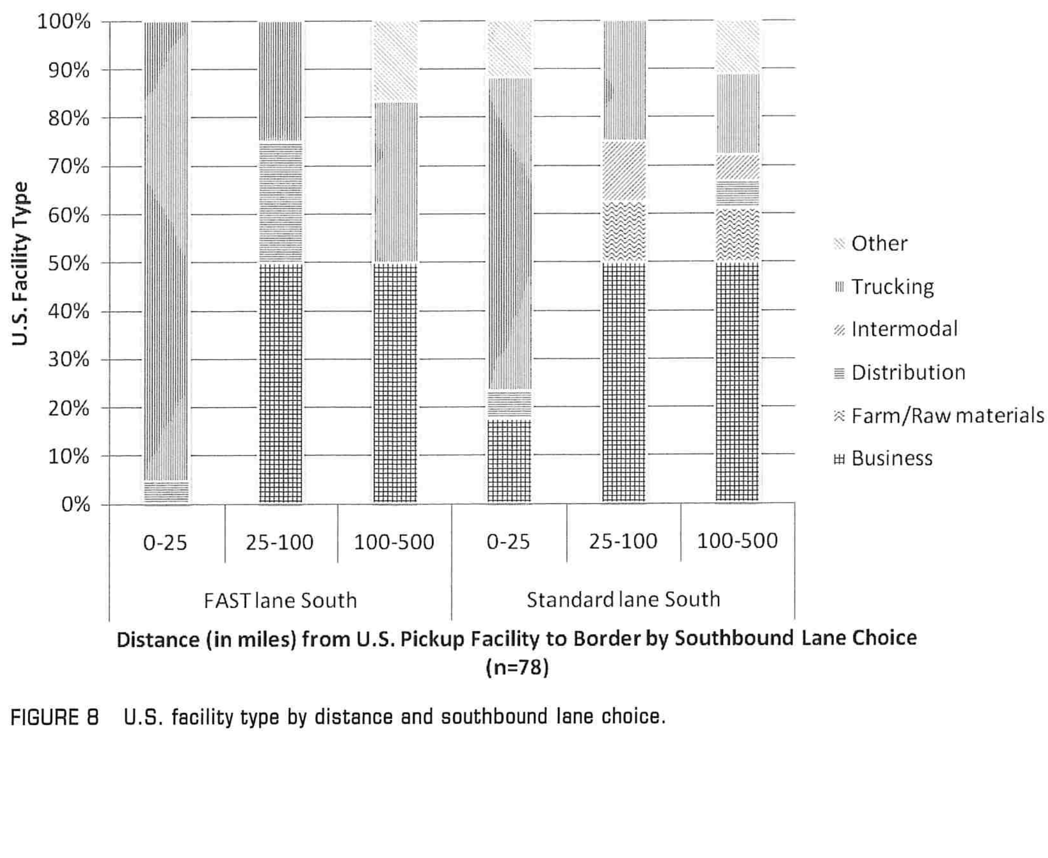

FIGURE 8 U.S. facility type by distance and southbound lane choice.

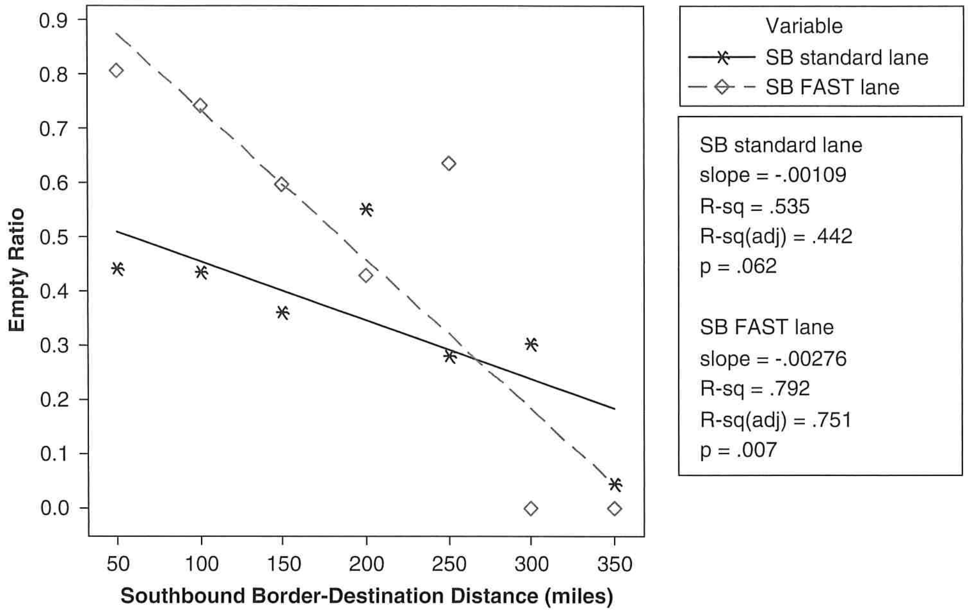

FIGURE 9 Southbound distances and load ratios by lane choice.

of inefficient near-border operations (near-border staging and empty trips), the data suggest that these inefficiencies are increased by the border and that FAST use correlates with amplified effects of these metrics. For trucks that deadheaded across the border to locations not far beyond the border crossing, those using the FAST lane were more likely to be destined for trucking facilities, while those using the standard lanes were more likely to be destined for distribution or business locations. Also, while proximity to the border correlates with higher rates of crossing the border empty, use of the FAST lane exaggerates this relationship. This suggests that FAST incentivizes trucks to cross empty at the Pacific Highway border rather than obtain a backhaul load.

This initial research into the topic of near-border logistics has provided interesting results and significant implications for border policy decisions. The magnitude of empty-trip rates using southbound FAST facilities is cause for concern. However, before making recommendations for policy or infrastructure changes, a more detailed understanding of industry-specific behaviors is needed. Future and ongoing research will collect additional data on border-crossing logistics so that industry-specific responses can be analyzed.

ACKNOWLEDGMENTS

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The International Trade and Transportation Committee peer-reviewed this paper.

Scheduling Under Uncertainty for Single-Hub Intermodal Freight System

Nikola Marković and Paul Schonfeld

This paper examines the optimization of an intermodal system with freight transfers at a single hub by determining when departures should be scheduled on outbound routes, given information about the probabilistic arrivals of vehicles on inbound routes. The intermodal system is modeled with stochastic programming, and the schedule of outbound vehicles is optimized with a genetic algorithm. The model is designed to minimize the expected total cost of operating an intermodal system while considering all capacity constraints arising in the real world. This model allows the system performance to be computed numerically, without the approximations of alternative methods such as simulation. Although the model can be applied to the most general case, the model seems to be especially suitable for analyzing systems with a relatively small number of arrivals on inbound routes. In particular, the model can be successfully applied to situations where statistical or queuing analyses are not applicable because of the small number of events (vehicle arrivals). The authors specifically analyze an intermodal system consisting of multiple inbound truck routes and multiple outbound airline routes. However, the mathematical model developed in this paper is applicable to other combinations of transportation modes.

Intermodal freight transport has many advantages that have encouraged its development during the last century. Reduced storage requirements and better use of infrastructure and transportation vehicles are just some of the characteristics that enable intermodal transport to outperform other transportation concepts. Nevertheless, intermodal freight transport includes operations and resources that tend to be expensive. Its overall system cost can be reduced by optimizing the transportation processes. Optimization of various aspects of intermodal transport is found in the literature.

Truck-to-air connectivity was studied by Hall (*1*). He points out the sorting process at the airport of origin as particularly critical and focuses on scheduling the start time for the sorting process. The airport terminal is modeled as a queuing system with random bulk arrivals, and predictions are provided for expectation and standard variation of arrived work. The key concept behind the model is conversion of truck schedules into forecasts for the expected arrival of work and its standard deviation. The methods developed provide a tool for representing the trade-off between sort productivity and the objective of completing the sort as early as possible.

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Ting and Schonfeld analyzed the transfer coordination in public transportation networks with stochastic travel times (*2*). Total system cost is used to evaluate the performance of coordination under different demand and arrival distributions. The authors analyzed three operations policies: uncoordinated, fully coordinated, and partially coordinated. Two heuristic algorithms were applied to optimize headways and slack times using integer multiples of base cycle. That work was extended to freight systems by Chen and Schonfeld, who developed a hybrid genetic algorithm (GA)–sequential quadratic programming method for optimizing the headways and slack times (*3*).

Quite a few authors have addressed the airline scheduling problem under stochastic demand. Teodorović developed models to measure the level of service by minimizing the time difference between actual and desired departure times (*4*). In the first model, he demonstrates that the time difference can be approximately expressed as a function of flight frequency only, without regard to the departure times during the day. In the second model and numerical example, he finds the optimal departure times with respect to minimal average schedule delay for a known demand and preassigned frequency on a route. The work of Teodorović was extended by Chang and Schonfeld, who developed an integrated model that allowed variability in flight departure times while resolving trade-offs between efficient fleet operation and quality of service (*5*).

In this paper, schedules are optimized on outbound routes in an intermodal freight system. This research determines when the operator should schedule the departures on outbound routes in order to minimize overall system cost. The model described in this paper is original and is not directly related to any models found in the literature. It represents an original work that bases the intermodal system analysis on the randomly distributed duration of vehicle round-trips on inbound routes. It is assumed that such an approach would provide greater precision than do some other models found in the literature. The system is modeled applying stochastic programming (*6*).

PROBLEM STATEMENT

Figure 1 shows intermodal freight system operations. Trucks gather the freight from locations spread around the terminal and unload it in the terminal's storage facilities. At terminal, the freight is further loaded into airplanes that transport it to multiple destinations. Moreover, when the takeoff on route l is scheduled at time t_i^l as much freight is loaded into the airplane as its capacity allows. If an airplane's capacity is exceeded, the remaining freight must wait for the next connecting flight with available capacity. Conversely, if there is little freight connecting to route l before the takeoff, the airplane's capacity is underused and an additional flight may be needed later.

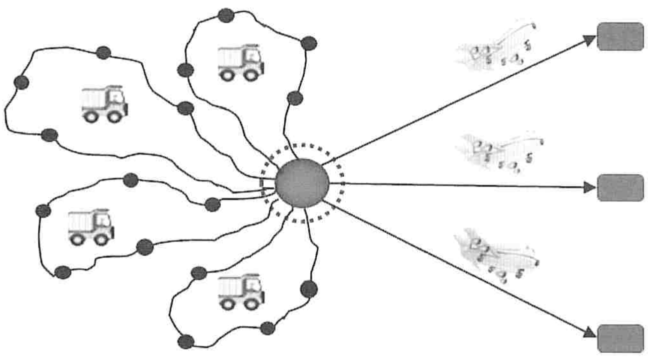

FIGURE 1 Intermodal freight system.

The objective is to optimize (*a*) the number of takeoffs on each route and (*b*) the corresponding schedule for the given probabilistic durations of truck round-trips. When optimizing the number of takeoffs and the schedule, certain constraints and assumptions are considered. As mentioned previously, airplane capacity must be taken into account. For simplicity, the authors assume that all aircraft have similar capacities. Also, capacity limits for the terminal's storage are considered so that the expected amount of freight will never exceed a preset multiple of terminal storage capacity (i.e., 80% of the capacity). And it is assumed that all trucks are similar and all operate at their equal maximum capacity. The last assumption, which can easily be relaxed, was primarily introduced to analyze a case of system recovery after a major disruption, during which much freight has accumulated at various warehouses.

The goal is to find the number of takeoffs and schedule them in a way that minimizes total system cost. In calculating total cost, the following are considered:

1. Storage cost, which refers to the cost of storing freight in the terminal's storage area while waiting for a connection;
2. Cost of in-terminal operations, including the cost of unloading and loading the freight (cost is lower if a truck arrives slightly before the takeoff and unloads directly onto the airplane);
3. Penalty for late delivery, reflecting a decrease in the value of the freight as delivery is delayed (instead of using a time value function, the authors introduce a penalty function that depends on the time that freight is loaded onto the airplane); and
4. Airline service cost that includes both airplanes and airport services.

A trade-off exists between the listed types of costs. The earlier the takeoff is scheduled, the lower are the first and third types of cost associated with the freight that successfully connects. However, the earlier the takeoff is scheduled, the greater are the chances that the airplane's capacity will remain unused because of late-arriving trucks. Having airplanes operate below capacity may require running additional flights, thereby increasing the fourth type of cost. To find (*a*) the number of takeoffs and (*b*) the takeoff schedule that minimizes the overall system cost, the total cost is formulated as a function of the number of takeoffs on each route and the associated takeoff times. The authors later use heuristics to minimize total system cost.

The remainder of this paper is organized into five sections. In the following section, the authors provide the formulation of the expected primary dwell time [E(PDT)]. The next section contains the formulation of the expected additional dwell time [E(ADT)] arising from limited airplane capacity. Both E(PDT) and E(ADT) and are needed for computing storage cost and are included in the formulation of the model. Through numerical examples the authors test the model, analyze the optimization results, and draw conclusions.

Finding *E*(PDT)

The dwell time is estimated in the terminal's storage from the moment the truckload arrives until the first connection upon its arrival. First, the PDT is formulated as a random variable. Then its mathematical expectation is found as a function of (*a*) the number of takeoffs and (*b*) the takeoff times. E(PDT) is derived comprehensively by starting from the simplest case and gradually developing it into its generic form.

Suppose that truck k is assigned a single round-trip whose duration (including loading and unloading times) is represented by random variable $X_{k,1}$ with probability density function (PDF) $f(x_{k,1})$. Moreover, assume that the truck's starting and end point is the terminal where the truckload should connect to one of n^l flights on route l, taking off at times $t_1^l, t_2^l, \ldots, t_{n^l}^l$. Further assume that if a truck misses all n^l takeoffs, its cargo must wait for the connection at time e^l on the following day. Finally, suppose that the probability that the truck will arrive at the terminal after time e^l is negligible, $P(X_{k,1} > e^l) \approx 0$. (See Figure 2.)

Cargo PDT represents a random variable that depends on the duration of round-trip $X_{k,1}$ as well as connection times $t_1^l, t_2^l, \ldots, t_{n^l}^l$ and e^l. If the PDT of the truckload carried by truck k and connecting to route l is denoted as $\mathrm{PDT}_{k,1}^l$, it is defined as follows:

$$\mathrm{PDT}_{k,1}^l = \begin{cases} t_1^l - X_{k,1}, & 0 < X_{k,1} < t_1^l \\ \cdots & \\ t_i^l - X_{k,1}, & t_{i-1}^l < X_{k,1} < t_i^l \\ \cdots & \\ e^l - X_{k,1}, & t_{n^l}^l < X_{k,1} < e^l \end{cases} \tag{1}$$

The expectation of $\mathrm{PDT}_{k,1}^l$ can be computed by the application of the law of unconscious statistician (*7*). If $t_0^l = 0$ and $t_{n^l+1}^l = e^l$, the E(PDT) of a truckload carried by truck k and connecting to route l is

$$E\left[\mathrm{PDT}_{k,1}^l\right] = \sum_{i=1}^{n^l+1} \int_{t_{i-1}^l}^{t_i^l} \left(t_i^l - x_{k,1}\right) f\left(x_{k,1}\right) dx_{k,1} \tag{2}$$

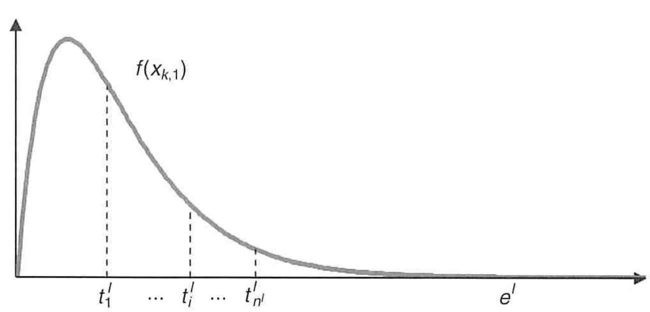

FIGURE 2 PDF of round-trip assigned to truck *k*.

The previous analysis can be extended to a more complex case in which a truck makes multiple round-trips. Consider the case where truck k is assigned r_k consecutive round-trips, all starting and ending at the terminal. At this point it can be assumed that the airplane departing at moment t_i^l always has enough capacity to pick up all the truckloads that were found at the terminal. If a random variable that describes the duration of the jth round-trip made by truck k is denoted as $X_{k,j}$, the random variable $Y_{k,j}$, which describes the jth truck arrival at the terminal, is given with the following sum:

$$Y_{k,j} = X_{k,1} + \cdots + X_{k,j-1} + X_{k,j} \tag{3}$$

The PDF of a variable $Y_{k,j}$ (Figure 3) is defined as the convolution of PDFs describing duration of j round-trips:

$$f(y_{k,j}) = f(x_{k,1}) * \cdots * f(x_{k,j-1}) * f(x_{k,j}) \tag{4}$$

Bearing in mind Equations 2, 3, and 4, the E(PDT) of the truckload carried by truck k in the jth round-trip can be defined as

$$E\left[\text{PDT}_{k,j}^l\right] = \sum_{i=1}^{n^l+1} \int_{t_{i-1}^l}^{t_i^l} \left(t_i^l - y_{k,j}\right) f\left(y_{k,j}\right) dy_{k,j} \tag{5}$$

If a truck were carrying truckloads connecting to route l in all round-trips, the E(PDT) of cargo from truck k would be calculated by summing Equation 5 for all the truckloads carried in r_k round-trips. However, because truckloads carried in some round-trips may not be connecting to airline route l, binary parameter $p_{k,j}^l$ is introduced; it is equal to one if truckload carried by truck k in the jth round-trip connects to route l; and equal to zero otherwise. The dwell time of cargo from truck k connecting to route l is given in Equation 6. The probability of the last round-trip ending after the takeoff scheduled on the following day is assumed to be negligible, $P(Y_{k,r_k}) > e^l \approx 0$.

$$E\left[\text{PDT}_k^l\right] = \sum_{j=1}^{r_k} p_{k,j}^l E\left[\text{PDT}_{k,j}^l\right] \tag{6}$$

The E(PDT) of freight connecting to airline route l and being transported by multiple trucks making multiple round-trips can now be computed. This can be done easily by summing Equation 6 for all v trucks in the intermodal freight system.

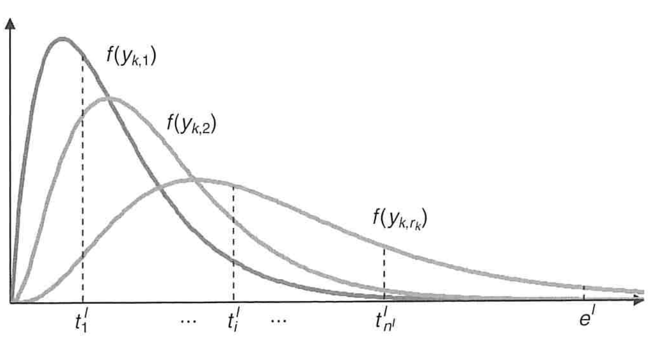

FIGURE 3 PDFs of first, second, and r_kth arrival of truck k.

$$E\left[\text{PDT}^l\right] = \sum_{k=1}^{v} E\left[\text{PDT}_k^l\right] \tag{7}$$

Finally, the expected dwell time for cargo connecting to all m outbound aircraft routes can be computed.

$$E\left[\text{PDT}\right] = \sum_{l=1}^{m} E\left[\text{PDT}^l\right] \tag{8}$$

Finding E(ADT)

Because the above calculation of the E(PDT) does not consider the possibility that a truckload might wait longer than period $(t_i^l - Y_{k,j})$ because of the limited capacity of airplanes, additional calculations are needed. For example, if the expected number of truckloads arriving in interval (t_{i-1}^l, t_i^l) and connecting to route l is greater than the capacity of an airplane taking off at moment t_i^l, ADT of cargo that cannot fit inside the plane must be considered.

In order to calculate the ADT, the expected number of connecting truckloads arriving in each of (t_{i-1}^l, t_i^l) intervals must be computed. The expectation will be calculated on the basis of the expected number of connecting truckloads arriving in $(0, t_i^l)$ interval, which is derived in the next section. Finally, at the end of this section an algorithm that computes E(ADT) is provided.

Expected Number of Connecting Truckloads Arriving in Interval 0, t_i^l

This expectation is derived starting from the simplest case, which includes a single truck. Suppose that truck k is assigned r_k consecutive round-trips and that the expected number of connecting truckloads arriving in interval $(0, t_i^l)$ must be calculated. To calculate this number, the probability that a arrivals occur within the $(0, t_i^l)$ interval must first be found. In other words, the probability that the first a round-trips end before t_i^l, while the subsequent round-trip ends after t_i^l must be calculated:

$$P(a) = P\left(X_{k,1} < t_i^l, \ldots, X_{k,1} + \cdots + X_{k,a} < t_i^l, X_{k,1} + \cdots + X_{k,a+1} > t_i^l\right) \tag{9}$$

The probability is given with an $(a + 1)$ – dimensional integral:

$$P(a) = \int_0^{t_i^l} dx_{k,1} \cdots \int_0^{t_i^l - x_{k,1} - \cdots - x_{k,a-1}} dx_{k,a} \int_{t_i^l - x_{k,1} - \cdots - x_{k,a}}^{+\infty} f\left(x_{k,1}, \ldots, x_{k,a+1}\right) dx_{k,a+1} \tag{10}$$

Note that $f(x_{k,1}, \ldots, x_{k,a+1})$ from Equation 10 represents the joint PDF of random variables $X_{k,1}, \ldots, X_{k,a+1}$. Because durations of round-trips are independent, the joint PDF can be obtained by simply multiplying $(a + 1)$ PDFs. (Arrivals are mutually dependent; however, the durations of individual round-trips are independent.)

$$f\left(x_{k,1}, \ldots, x_{k,a+1}\right) = \prod_{j=1}^{a+1} f\left(x_{k,j}\right) \tag{11}$$

After the probability of a arrivals in interval $(0, t_i^l)$ is computed, the expected number of arrivals of truck k in the interval can be calculated as

$$\sum_{a=1}^{r_k} P(a)a \tag{12}$$

However, truck k may not be carrying freight connecting to route l in all r_k round-trips. Thus, $P(a)$ should not be multiplied with the number of arrivals, so that the expected number of arriving truckloads connecting to route l can be calculated. Instead, binary parameter $p_{k,j}^l$ is again used, expressing the expected number of truckloads delivered by truck k in interval $(0, t_i^l)$ and connecting to route l as follows:

$$E\left[\mathrm{TR}_k^l\left(0, t_i^l\right)\right] = \sum_{a=1}^{r_k} P(a) \sum_{j=1}^{a} p_{k,j}^l \tag{13}$$

Now, the general case including multiple trucks making multiple round-trips can be considered. For this case, the expected number of truckloads connecting to route l and arriving at the terminal in interval $(0, t_i^l)$ can be obtained by simply summing Equation 13 for all v trucks.

$$E\left[\mathrm{TR}^l\left(0, t_i^l\right)\right] = \sum_{k=1}^{v} E\left[\mathrm{TR}_k^l\left(0, t_i^l\right)\right] \tag{14}$$

Expected Number of Connecting Truckloads Arriving in Interval t_{i-1}^l, t_i^l

Computing the expected number of truckloads connecting to route l and arriving at the terminal in interval $(0, t_i^l)$ produces a result for calculating the expected number of truckloads connecting to route l and arriving at the terminal in interval (t_{i-1}^l, t_i^l), which is denoted as $E[\mathrm{TR}^l(t_{i-1}^l, t_i^l)]$ and equals the expected number of truckloads arriving at the terminal in $(0, t_i^l)$ minus the expected number of truckloads arriving in $(0, t_{i-1}^l)$.

$$E\left[\mathrm{TR}^l\left(t_{i-1}^l, t_i^l\right)\right] = E\left[\mathrm{TR}^l\left(0, t_i^l\right)\right] - E\left[\mathrm{TR}^l\left(0, t_{i-1}^l\right)\right] \tag{15}$$

With this expectation now known, the expected number of connecting truckloads arriving between consecutive flights can be determined, allowing the expected additional dwell time that occurs because of limited airplane capacity to be estimated.

Algorithm for Computing E(ADT)

The algorithm for computing E(ADT) for cargo connecting to route l uses the previously derived expectation $E[\mathrm{TR}^l(t_{i-1}^l, t_i^l)]$. For the given takeoff times, it examines the expected number of truckloads arriving between consecutive flights and determines whether their number exceeds the airplane's capacity (A_c). If it exceeds A_c, the algorithm computes associated additional dwell time and adds it to $E(\mathrm{ADT}^l)$.

After denoting as s_i^l the number of truckloads connecting to route l that were left in storage after the ith takeoff and assigning initial values of zero to s_i^l and $E[\mathrm{ADT}^l]$, the expected additional dwell time for the cargo connecting to route l can be computed with the recursive formula given in Equations 16 through 19.

$$E\left[\mathrm{ADT}^l\right] = 0;\ s_0^l = 0; \tag{16}$$

$$\text{for } i = 1 \text{ to } n^l \tag{17}$$

$$s_i^l = \max\left\{0,\ s_{i-1}^l + E\left[\mathrm{TR}^l\left(t_{i-1}^l,\ t_i^l\right)\right] - A_c\right\} \tag{18}$$

$$E\left[\mathrm{ADT}^l\right] = E\left[\mathrm{ADT}^l\right] + s_i^l\left(t_{i+1}^l - t_i^l\right) \tag{19}$$

Finally, after the expected additional dwell for cargo connecting to route l has been computed, the total additional dwell time can be calculated by simply summing Equation 19 for all m outbound routes.

$$E\left[\mathrm{ADT}\right] = \sum_{i=1}^{m} E\left[\mathrm{ADT}^l\right] \tag{20}$$

MODEL FORMULATION

As previously stated, the objective is to minimize total system cost while satisfying certain constraints. In this section, the authors first discuss types of costs considered and then formulate the total cost function. In the following section, anticipated constraints are explained and their compact formulation provided. The mathematical formulation of the model is given in the last part of this section. Finally, it should be noted that throughout the following work the authors use expectations and the algorithm developed above. The remainder of the paper shows that two expectations and the algorithm are crucial for calculating cost components and formulating terminal storage constraint.

Total Cost Function

The four types of cost listed in the problem statement are considered, beginning with the storage cost. Because how to calculate the E(PDT) as well as the E(ADT) are known, the expected number of truckload hours of dwell time in terminal storage can be calculated. To obtain the storage cost (SC), the sum of the two expectations are multiplied with the unit storage cost (C_{DT}):

$$\mathrm{SC} = \left(E\left[\mathrm{PDT}\right] + E\left[\mathrm{ADT}\right]\right)C_{\mathrm{DT}} \tag{21}$$

As previously argued, the cost of in-terminal operations can be reduced when a truck arrives at the terminal slightly before the takeoff and takes its truckload directly to the aircraft. Thus, cost of in-terminal operations is sensitive to the schedule of takeoffs and should be considered in the optimization. Because the expected number of connecting truckloads arriving in a certain interval can be formulated by Equation 15, the expected number of truckloads unloaded directly onto aircraft can be estimated. First, Δt is denoted as the time interval such that a truck arriving within the $(t_i^l - \Delta t, t_i^l)$ will unload directly onto the airplane departing at t_i^l. Now the expected number of truckloads connecting to route l that will be transferred directly from truck to airplane can be defined.

$$b_d^l = \sum_{i=1}^{n^l} E\left[\mathrm{TR}^l\left(t_i^l - \Delta t,\ t_i^l\right)\right] \tag{22}$$

To find the total number of truckloads loaded directly to airplanes, Equation 22 should be summed for all m airplane routes:

$$b_d = \sum_{l=1}^{m} \sum_{i=1}^{n^l} E\left[\mathrm{TR}^l\left(t_i^l - \Delta t,\ t_i^l\right)\right] \tag{23}$$

It is clear that remaining truckloads will be processed regularly and that another cost will be associated with them. Denote as C_{td} the cost of in-terminal operations for the case where truck takes truckload directly to the airplane. Moreover, denote as C_{tr} the cost of in-terminal operations where the freight is processed regularly. Finally, if the overall number of truckloads is denoted as g, the total in-terminal operation cost (IC) is

$$\mathrm{IC} = b_d C_{td} + \left(g - b_d\right) C_{tr} \tag{24}$$

To estimate the late delivery penalty, the time-dependent penalty function $f_p(t_i^l)$ is formulated, assuming that the takeoff time t_i^l is relevant for calculating the penalty. For example, if h_i^l truckloads are loaded on the flight taking off at t_i^l, the corresponding penalty will be $h_i^l f_p(t_i^l)$. The penalty cost associated with truckloads carried on all $n^l + 1$ flights on route l (PC^l) is given in Equation 25. Note that $t_{n^l+1}^l = e^l$.

$$\mathrm{PC}^l = \sum_{i=1}^{n^l+1} h_i^l f_p\left(t_i^l\right) \tag{25}$$

However, the problem with Equation 25 is that it cannot be known in advance how many truckloads will be loaded into the airplane departing at t_i^l. Therefore, an algorithm is needed that computes the penalty cost for the given t_i^ls. Similar to the algorithm in the previous section, the penalty cost can be computed using a recursive formula given in Equations 26 through 29. Again, the expected number of connecting truckloads arriving in the (t_{i-1}^l, t_i^l) interval will be used.

$$\mathrm{PC}^l = 0;\ h_0^l = 0 \tag{26}$$

$$\text{for } i = 1 \text{ to } n^l + 1 \tag{27}$$

$$h_i^l = \min\left\{A_c,\ s_{i-1}^l + E\left[\mathrm{TR}^l\left(t_{i-1}^l, t_i^l\right)\right]\right\} \tag{28}$$

$$\mathrm{PC}^l = \mathrm{PC}^l + h_i^l f_p\left(t_i^l\right) \tag{29}$$

To calculate the total penalty cost associated with truckloads loaded at all m outbound routes, Equation 29 must be summed for all airplane routes:

$$\mathrm{PC} = \sum_{l=1}^{m} \mathrm{PC}^l \tag{30}$$

The last type of cost considered is the airline service cost, which refers to the use of both airplanes and airport facilities. It is proportional to the number of flights (i.e., number of takeoffs). The number of takeoffs on route l will be denoted as n^l, and the cost of an airplane trip on route l will be denoted as C_A^l. Thus the airline service cost (AC) for all routes is

$$\mathrm{AC} = \sum_{l=1}^{m} \mathrm{AC}^l = \sum_{l=1}^{m} n^l C_A^l \tag{31}$$

Finally, after the storage cost, in-terminal operation cost, penalty cost, and airline cost are defined, the total cost (TC) represents the sum of the four cost types:

$$\mathrm{TC} = \mathrm{SC} + \mathrm{IC} + \mathrm{PC} + \mathrm{AC} \tag{32}$$

Constraints

The constraint on airplane capacity has already been considered by calculating the E(ADT). However, the constraint on maximum storage capacity has not yet been included. Moreover, since the takeoff times might be restricted to certain intervals, time windows for takeoffs will be considered. Finally, minimum headway constraints for takeoffs will be included.

To ensure that the expected amount of freight never exceeds the preset multiple of terminal storage capacity (i.e., 80% of storage capacity), a vector (**T**) is defined such that its elements represent takeoff times on all m outbound routes organized in ascending order. Element t_i^l represents the ith takeoff from the terminal, and s_i denotes the total amount of freight left in terminal after the ith takeoff, similar to s_i^l in the algorithm of Equations 16 through 19. If n denotes the total number of takeoffs from the terminal and $E[\mathrm{TR}(t_{i-1}, t_i)]$ is the expected total number of truckloads arriving between two consecutive flights, the storage constraint is given in Equation 33. Note that $t_0 = 0$, $s_0 = 0$, and multiple of storage capacity is given as $m_c S_c$.

$$s_{i-1} + E[\mathrm{TR}(t_{i-1}, t_i)] \le m_c S_c \qquad i = 1, \ldots, n \tag{33}$$

The time window constraint for takeoffs is also considered. Because the use of airport facilities is often restricted to certain time slots, each of the n takeoff times must occur within a corresponding time window. Moreover, time windows may be restricted by the preferred delivery times.

$$a_i < t_i < b_i \qquad i = 1, \ldots, n \tag{34}$$

Finally, it is assumed that limited airport capacity may require a minimum time interval between any two takeoffs.

$$t_i - t_{i-1} \ge t_{\min} \qquad i = 2, \ldots, n \tag{35}$$

Mathematical Formulation of Model

In the previous section, the types of costs and constraints considered were explained. Here the mathematical formulation of the model is provided in Equations 36 through 39, which represent a stochastic mathematical program.

$$\min \mathrm{TC} = \mathrm{SC} + \mathrm{IC} + \mathrm{PC} + \mathrm{AC} \tag{36}$$

subject to

$$s_{i-1} + E\left[\mathrm{TR}\left(t_{i-1},\ t_i\right)\right] \le m_c S_c \qquad i = 1, \ldots, n \tag{37}$$

$$a_i < t_i < b_i \qquad i = 1, \ldots, n \tag{38}$$

$$t_i - t_{i-1} \ge t_{\min} \qquad i = 2, \ldots, n \tag{39}$$

NUMERICAL EXAMPLES

To test the mathematical formulation, two numerical examples are designed. The first case includes a single aircraft outbound route, while the second case deals with multiple outbound routes. For the first case, a sensitivity analysis is also provided, where the trade-offs in types of costs listed in the introductory section of this paper are studied. For both cases, a genetic algorithm is used to optimize the schedules (*8*). An off-the-shelf GA toolbox that performed well in the observed case studies is used (*9*). In order to decrease the chances of the GA getting stuck in a local minimum, each optimization was repeated several times with different input parameters such as initial population, population size, and crossing-over function. The population size was varied between 10 and 15 individuals, while several available options (scattered, one-point, and two-point) were tested for the crossing-over function. Finally, because the GA is not guaranteed to find an optimal solution, solutions are referred to as optimized rather than optimal.

Case with Single Outbound Route

A numerical example is developed that includes 12 truck assignments conducted by four trucks. Input data are shown in Table 1. Each truck is assigned three consecutive round-trips, all exponentially distributed with average duration time given in Table 2. Assuming the remaining inputs from Table 2, the goal is to optimize the number of takeoffs and corresponding schedule.

The optimization results for three, four, five, six, and seven takeoffs are presented in Table 3. An optimized schedule is presented for five different numbers of takeoffs and corresponding costs. The category "other costs" considers storage, penalty, loading, and unloading cost. Through marginal savings in these other costs, the authors consider savings in storage, penalty, loading, and unloading cost attributable to introducing an additional flight.

The results presented in Table 3 show that the total cost was minimized in the case with four takeoffs. Therefore it was concluded that at the cost of 2,000 monetary units/round-trip, one more flight than necessary to satisfy the demand should be introduced. And it can be observed that storage, penalty, loading, and unloading costs decrease with the increase in the number of takeoffs. This outcome was expected and confirmed the trade-off between types of cost that were explained in the problem statement. It is also noted that the marginal savings in storage, penalty, loading, and unloading cost decrease with the number of aircraft round-trips, which is another anticipated outcome.

How different flight costs affect the optimized number of takeoffs, and hence the schedule, can be explored on the basis of the values for storage, penalty, loading, and unloading cost. In Figure 4, total cost for three, four, five, six, and seven flights versus flight cost is plotted. Figure 4 shows four threshold values for airplane round-trip cost, which determine the optimized number of takeoffs. Those values are 234, 377, 660, and 2,444 monetary units, respectively. Clearly, for a relatively low aircraft round-trip cost, the total system cost is optimized by scheduling more takeoffs than necessary to satisfy the demand. As the airline cost increases, the optimized number of takeoffs decreases until it eventually drops to the minimum number needed to satisfy the demand.

TABLE 1 Input Data for Case with Single Outbound Route

Function	Variable	Amount
Airplane capacity	A_c	Five truckloads
Aircraft cost	C_A^1	2,000 MU/flight
Multiple of storage capacity	$m_c S_c$	Eight truckloads
Storage cost	SC	40 MU/truckload × h
Amount of time	Δt	15 min
In-terminal cost	C_{tr}	150 MU/truckload
	C_{td}	50 MU/truckload
Time of the last takeoff	e^1	30 h
Penalty function	$f_p(t)$	0 if $t \le 2$
		$125t - 250$ if $2 < t \le 10$ MU/truckload
		1,000 if $t > 10$

NOTE: MU = monetary units.

TABLE 2 Exponentially Distributed Truck Round-Trip Durations

Truck	1st Round-Trip (h)	2nd Round-Trip (h)	3rd Round-Trip (h)
1	$1/\lambda = 1.5$	$1/\lambda = 1.3$	$1/\lambda = 0.8$
2	$1/\lambda = 0.9$	$1/\lambda = 0.6$	$1/\lambda = 1.2$
3	$1/\lambda = 1.0$	$1/\lambda = 0.7$	$1/\lambda = 1.4$
4	$1/\lambda = 0.5$	$1/\lambda = 1.1$	$1/\lambda = 1.3$

TABLE 3 Optimized Schedules and Costs

Number of Flights	Total Aircraft Cost	Other Cost	Marginal Savings in Other Cost	Total Cost	Takeoff Times for Flight 1	2	3	4	5	6	7
3	6,000	7,042	NA	13,042	1.21	3.45	30.00	NA	NA	NA	NA
4	8,000	4,598	2,444	12,598	1.21	3.13	6.14	30.00	NA	NA	NA
5	10,000	3,938	660	13,938	1.21	2.47	4.19	7.10	30.00	NA	NA
6	12,000	3,561	377	15,561	0.84	2.00	3.22	4.98	7.61	30.00	NA
7	14,000	3,327	234	17,327	0.80	2.00	2.80	3.98	5.56	8.10	30.00

NOTE: NA = not applicable.

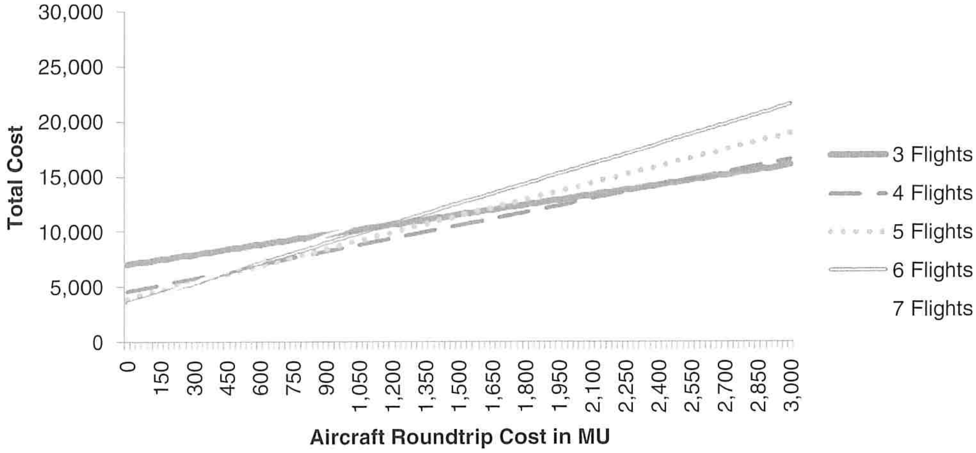

FIGURE 4 Sensitivity analysis.

TABLE 4 Input Data for Case with Multiple Outbound Routes

Function	Variable	Amount
Flight cost on route l	C_A^1	4,000 MU/flight
	C_A^2	4,800 MU/flight
	C_A^3	4,500 MU/flight
Multiple of storage capacity	$m_c S_c$	15 truckloads
Storage cost	SC	40 MU/truckload × h
In-terminal cost	C_{tr}	150 MU/truckload
	C_{td}	50 MU/truckload
Penalty function	$f_p(t)$	0 if $t \leq 2$
		$125t - 250$ if $2 < t \leq 10$
		1,000 if $t > 10$
Last takeoff on route l	e^1	30 h
	e^2	31 h
	e^3	32 h
Minimum time between two takeoffs	$t_{\min}$	0.5 h
Amount of time	Δt	15 min
Time window for the first takeoff on Route 1	(a,b)	(2, 3) h
Time window for the first takeoff on Route 2	(a,b)	(1.5, 2.1) h

TABLE 5 Exponentially Distributed Truck Roundtrip Duration and Connecting Airplane Route

Truck	1st Round-Trip (h)	Connecting Route l	2nd Round-Trip (h)	Connecting Route l	3rd Round-Trip (h)	Connecting Route l
1	$1/\lambda = 1.13$	2	$1/\lambda = 1.65$	3	$1/\lambda = 1.47$	2
2	$1/\lambda = 0.76$	3	$1/\lambda = 1.27$	2	$1/\lambda = 1.59$	1
3	$1/\lambda = 0.58$	2	$1/\lambda = 0.96$	1	$1/\lambda = 0.62$	2
4	$1/\lambda = 1.39$	1	$1/\lambda = 1.83$	3	$1/\lambda = 0.76$	1
5	$1/\lambda = 1.53$	2	$1/\lambda = 0.99$	3	$1/\lambda = 1.33$	1
6	$1/\lambda = 0.51$	3	$1/\lambda = 1.52$	1	$1/\lambda = 1.09$	3
7	$1/\lambda = 1.19$	1	$1/\lambda = 1.11$	3	$1/\lambda = 1.10$	1
8	$1/\lambda = 0.94$	1	$1/\lambda = 1.64$	3	$1/\lambda = 1.76$	3
9	$1/\lambda = 1.56$	2	$1/\lambda = 1.96$	2	$1/\lambda = 1.70$	1
10	$1/\lambda = 1.42$	2	$1/\lambda = 1.95$	1	$1/\lambda = 1.07$	3
11	$1/\lambda = 0.94$	3	$1/\lambda = 1.63$	2	$1/\lambda = 1.99$	1
12	$1/\lambda = 1.68$	3	$1/\lambda = 1.77$	3	$1/\lambda = 1.14$	2

TABLE 6 Optimization Summary

Aircraft, Route l	Number of Flights on l	Aircraft Cost on l	Other Cost on l	Takeoff Times on Route l			Total Cost
1	3	12,000	8,180	2.37	5.10	30	
2	3	14,400	6,447	1.87	4.60	31	63,770
3	3	13,500	9,243	1.37	3.74	32	

Case with Multiple Outbound Routes

A numerical example is designed to include multiple outbound routes. Input data are shown in Table 4. In Table 5, the mean for truck round-trip duration is provided, as well the connecting airplane route for the carried truckload. Again, all the round-trips are exponentially distributed. This time, the case is considered with 12 trucks making three round-trips, and freight connecting to three air routes. Adopting the inputs from Table 3, six takeoff times are optimized on three outbound airplane routes, considering the maximum terminal storage capacity, minimum time between takeoffs, and time windows for two takeoffs. Table 6 provides optimization results. "Other cost" in Table 4 refers to storage, penalty, loading, and unloading cost.

CONCLUSIONS

For the given probabilistic arrivals of vehicles on inbound routes in a single-terminal intermodal freight system, a model is developed that optimizes the schedule of vehicles on outbound routes. The model is designed to minimize the total cost of a system with transfers at one hub. It can be applied to very general cases but seems especially suitable for applications with relatively few vehicle arrivals on inbound routes. The model's complex and exact mathematical formulation improves its precision but decreases the solvable problem size. Therefore, this proposed model is most suitable for optimizing intermodal systems in situations where statistical or queuing analyses are less preferable because of the small number of events (vehicle arrivals), or when high variance appears in simulation analysis (*10*).

A GA toolbox was used to optimize the schedule in two case studies. The GA toolbox performed well in the observed case studies, but the authors recommend development of a customized GA for the analysis of larger systems. Sensitivity analysis confirmed the anticipated trade-off in types of cost. In numerical examples, the authors analyzed systems with inbound truck routes and outbound airline routes. However, the mathematical model developed in this paper can be applied to other combinations of transportation modes.

Furthermore, the model can be successfully applied to normal everyday operations, as well as to system recovery after major disruptions. Normal operations usually include complex multi-stop routes, because no single destination generates enough demand to fill a vehicle. Conversely, when demand accumulates while the system is perturbed by a major disruption, it tends to be more efficient to operate the vehicles on nonstop shuttle routes. Because the inputs to the model are probabilistic durations of vehicle round-trips, the model can be applied to both complex multi-stop routes and direct shuttle routes. Thus, the model presented here can be used for optimizing the schedule of vehicles on outbound routes for normal operations as well as for re-optimizing the system with a new routing policy introduced during periods of system recovery.

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Alleviating Schedule Disruptions at Intermodal Freight Transfer Terminals

Real-Time Dispatching Control

Cheng-Chieh (Frank) Chen and Paul Schonfeld

This study develops methods for countering schedule disruptions in intermodal or intramodal freight transportation systems operating in time-dependent, stochastic, and dynamic environments. When routine disruptions occur (e.g., traffic congestion, vehicle failures, or demand fluctuations) in preplanned intermodal timed-transfer systems, this dispatching control model determines through an optimization process whether each ready outbound vehicle should be dispatched immediately or held waiting for some late-incoming vehicles with connecting freight. Another submodel is developed to deal with the freight left over because of missed connections. Through a series of cases solved with a hybrid genetic algorithm–sequential quadratic programming algorithm, the model demonstrates its ability to minimize net costs through its dispatching decisions.

As awareness of the effect of globalization and information technology on the patterns of transport and logistic activities has increased, so has interest in the integration of intermodal transport resources. Intermodal freight transport is defined as the use of two or more modes to move a shipment from origin to destination—a move that involves the physical infrastructure, goods movement and transfer, and other relevant activities under a single freight bill (*1*).

Most operations at intermodal freight terminals require transfer movements from one mode to others to serve cargoes with diverse destinations, especially for break-bulk, cross-docking, or transshipment systems. Chen and Schonfeld developed a timed-transfer model for intermodal freight systems that, based on different coordination policies, quantifies and jointly optimizes the service frequencies and slack times of all routes in a given network (*2*). The potential benefits of such integrated coordination of transportation schedules include

1. Obviating the need for providing direct routes connecting all origin–destination (O-D) pairs and concentrating cargoes on major routes with faster (e.g., airplanes) or lower-cost (e.g., container ships) modes, results that also imply the economy of scale in transportation;
2. Improving the use of existing transportation infrastructure;
3. Reducing the requirements for warehouses and storage areas that result from poor connections; and
4. Reducing other impacts such as traffic congestion, fuel consumption, and emissions.

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Although the timed-transfer model can optimize operational schedules based on the expected environments and O-D information, service disruptions may occasionally occur and affect the system operations. Disruptions can be classified as routine or major; these classes require different response strategies. Routine disruptions represent the schedule perturbations caused by the stochastic uncertainties (e.g., traffic congestion, vehicle failures, or demand fluctuations) that tend to have moderate effects and short-term impacts. Major disruptions (e.g., storms, earthquakes, or terrorist attacks) are defined as situations occurring during an operation's execution that cause sufficiently large deviation from the plan so that the plan has to be changed substantially (*3*). Although routine disruptions are less severe than major ones, they occur more frequently and indeed require an efficient tool for managing them.

Managing disruptions is an important issue in scheduling operations. When disruptions occur, the previously optimized schedules may become far from optimal (or even infeasible), and means are needed for adjusting or re-optimizing the original plan to adapt to the changing environment and to get back on track in a timely manner, while effectively using the available resources.

Disruption management has been widely applied in the airline field in recent years. Clarke provides an overview of operation control during the post-disruption phases (*4*). He analyzes how airlines can reassign aircraft to scheduled flights after a disruptive situation. Clausen et al. summarize the developments of disruption management from an operations research viewpoint in airline operations, shipbuilding, and telecommunications (*3*). Kohl et al. provide a description of the planning processes in the airline industry (*5*). They report on experiences gained in managing major disruptions for airlines. Ball et al. describe the infrastructure and constraints of airline operations and develop optimization and simulation models for aircraft, crew, and passenger recovery (*6*). Liu et al. present a method for generating an aircraft routing algorithm in response to the schedule disruption of short-haul flights (*7*). In general, passengers are given a relatively low priority or even ignored in the airline disruption management references, which usually focus on crew and flight scheduling.

Several studies also consider disruption management in logistics. Rice and Caniato note that disruptions occurring at any point in the supply chain may cause failures of the entire system (*8*). Qi et al. investigate a supply chain coordination problem with a disruption caused by demand uncertainties (*9*). They find that such disruptions may impose considerable penalty costs on suppliers. Wu et al. present a model for analyzing how disruptions propagate and affect the supply chain system (*10*).

The authors' previous logistic timed-transfer models (*2*) develop coordinated and optimized schedules for given freight networks; the models minimize transfer delays and affect other factors. However,

in systems subject to variability in traffic conditions and demand fluctuations, some routine disruptions are inevitable. In this study, a real-time dispatching control model focuses on decisions made in response to disruptions of vehicle dispatching from transfer terminals that occur before all expected loads are on board. Through an optimization process, the proposed model determines which ready outbound vehicles (if any) should wait for specific other arriving vehicles. The "ready" outbound vehicles are ready to depart but may be deliberately held, waiting for some of the late vehicles in order to reduce the number of missed-connection delays. It should be noted that holding decisions at transfer terminals should be based on overall trade-off considerations. The authors develop probabilistic evaluation functions to combine and minimize the various costs of leaving sooner (and thus missing some freight, especially from connecting vehicles that have not yet arrived), or leaving later (and thus delaying freight already on board or waiting downstream, and possibly missing downstream connections).

Another optimization model was developed for redistributing cargoes that missed their transfers when dispatching decisions were made (i.e., for some vehicles that arrived after the intended receiving vehicles had left). The freight left over is then reassigned to the next vehicles departing on the appropriate routes, based on their remaining spaces and priorities of cargoes. This proposed model is designed generally enough to consider transfers among or within various modes, as long as the mode and route characteristics (e.g., demand, travel time distributions, vehicle capacities, and operating costs) are specified.

The remainder of this paper is organized as follows:

- Relevant optimization problems are described in detail;
- Methods for real-time control of schedule deviations are developed on the basis of given service routes, schedules, vehicles, and terminals;
- Multiple commodities with different time value functions are considered; and
- Some numerical examples are presented for evaluating the best dispatching decisions.

MODEL ASSUMPTIONS AND FORMULATIONS

The core concepts for integrating the treatments of routine service disruptions are illustrated in Figure 1. Stage 1 preplans an intermodal logistic timed-transfer system in ways that minimize transfer delays and unreliability, largely by coordinating schedules and optimizing the slack times (i.e., reserve or safety factors) within those schedules. In Stage 2, the real-time information and relevant data are collected when disruptions occur and affect the timed-transfer operations. In Stage 3, the authors attempt to optimize the dispatching decisions made in response to disruptions in time-dependent, stochastic, and dynamic environments.

The mathematical model for disruption response is based on independent dispatching decisions for different ready outbound routes. The routes and terminal locations within the network are predetermined. Three different coordinated methods are defined in our previous study (*2*): namely, uncoordinated operations, coordinated operations with a common service headway, and coordinated operations with integer–ratio service headways. Uncoordinated operation means that all modes and routes are optimized independently; other coordination methods are developed for different characteristics and combinations of modes.

When routine disruptions occur, the real-time dispatching decisions consider all routes that are mutually coordinated at the transfer terminals. Uncoordinated routes will be dispatched on the basis of originally scheduled departure times. It should be noted that several related models have been developed for urban passenger transportation and air transportation systems (*11, 12*); however, some important differences pertaining to freight logistics (e.g., factors affecting demand, lack of self-guidance, storage requirements, perishability, heterogeneous characteristics of cargoes, and information availability about shipments) require special attention in this study.

Optimized Problem for Real-Time Dispatching Control in Response to Schedule Disruptions

Let $G(N, E)$ denote a directed transportation network, where N is a set of nodes and E is a set of links. The authors define $i \in I$ as the ready vehicles on outbound routes and $j \in J$ as the late vehicles on inbound routes; each route contains several nodes and links.

It is assumed that there is no further interrelation among the ready routes during the decision time; thus, holding or dispatching decisions are independent for each ready vehicle. The model is expressed as follows:

$$\text{minimize } Z_i^k = y_i C_{n,i}^k + (1 - y_i) C_{h,i}^k \tag{1}$$

where Z is the minimized objective value (i.e., total costs resulting from holding or not holding).

The minimized objective function (Equation 1) is formulated as the sum of costs resulting from holding or not holding. For each ready vehicle i at the terminal k, y_i is a binary decision variable representing whether to hold ($y_i = 0$) for any late inbound vehicle or to dispatch immediately ($y_i = 1$). $C_{n,i}$ and $C_{h,i}$ represent the system net costs caused by dispatching (i.e., not holding) and holding decisions, respectively.

$$C_{n,i}^k = \sum_{m \in M} \sum_{j \in J} \mu^m q_{ji}^{mk} h_j \delta_i^k \delta_j^k \times \left[h_i - \int_{s_j^k}^{h_j} t \, f_j^d(t) \, dt \right] \tag{2}$$

If the ready outbound vehicles are dispatched immediately, without holding for any late vehicle, the sum of total missed-connection costs ($C_{n,i}^k$) for transfer cargoes from late inbound routes is expressed in Equation 2. The additional dwell time of waiting for the next vehicle is formulated as the service headway minus the probabilistic late arrival time. The authors assume that delay probability density function ($f_j^d(t)$) can be estimated with real-time monitor systems. μ^m equals unit time cost of type m cargo (\$/lb-h); q_{ji}^{mk} equals amount of type m cargo transferred at the terminal k from route j to route i (lb/h); h_i equals preoptimized service headway of route i (h); δ_i^k (a binary variable) equals 1 if terminal k is connected to route i and 0 otherwise; s_j^k equals slack time at terminal k on route j (min).

The probability of lateness for any inbound vehicle is illustrated in Figure 2*a*, in which $f(t)$ equals probability density function of arrival time, $f^0(t)$ equals the probability density function for preplanned vehicle arrival time, and $f^d(t)$ equals the probability density function for vehicle late arrival time. In Figure 2*b*, the shadowed area illustrates the probability that a late vehicle arrives after the holding time T_i.

Equation 3 expresses the sum of costs generated by holding vehicle i until late vehicle j^* arrives ($j^* \leq j$). To simplify this problem, it is assumed that holding decisions would mainly affect the current

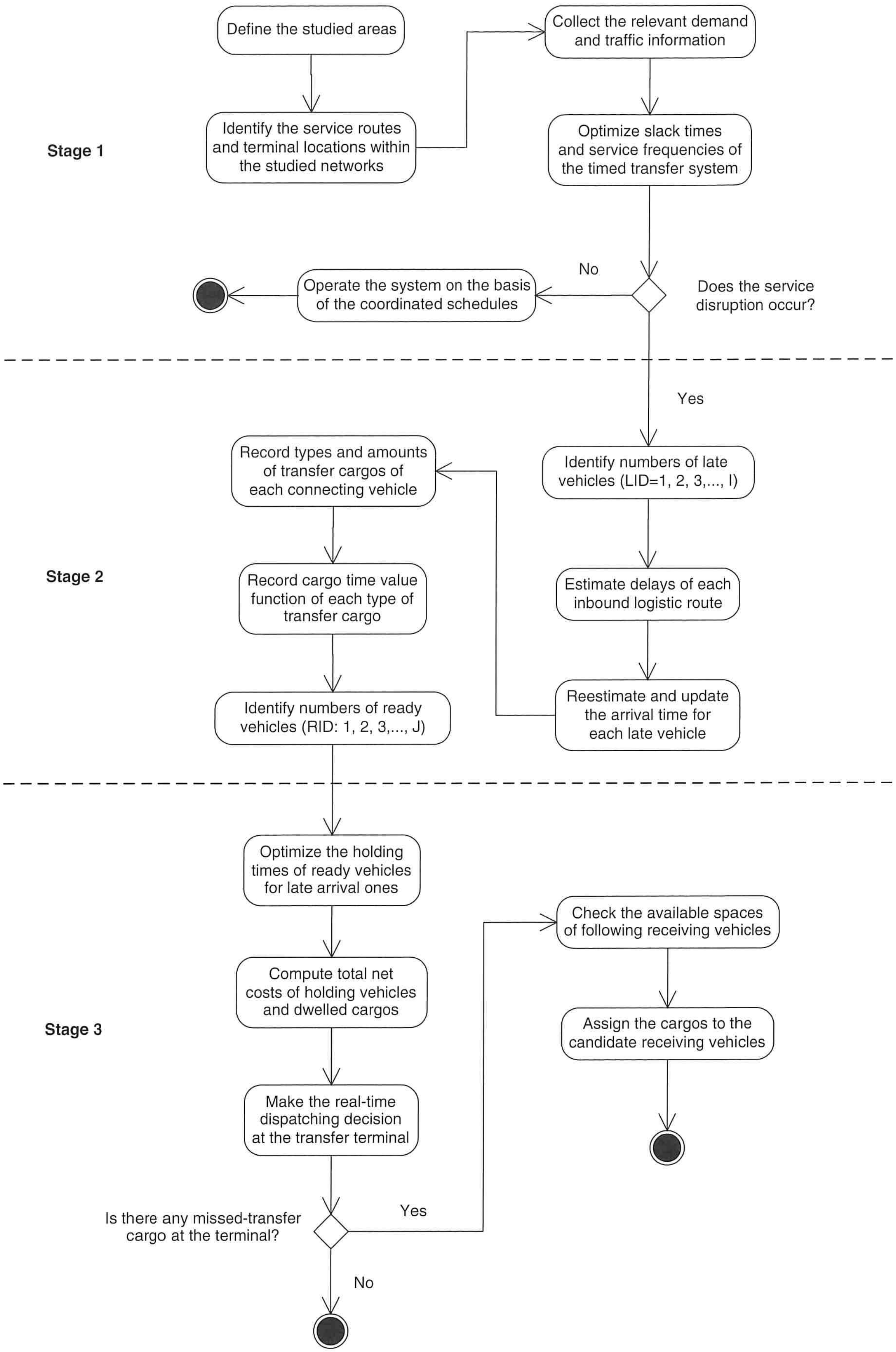


FIGURE 1 Flowchart for real-time dispatching control.

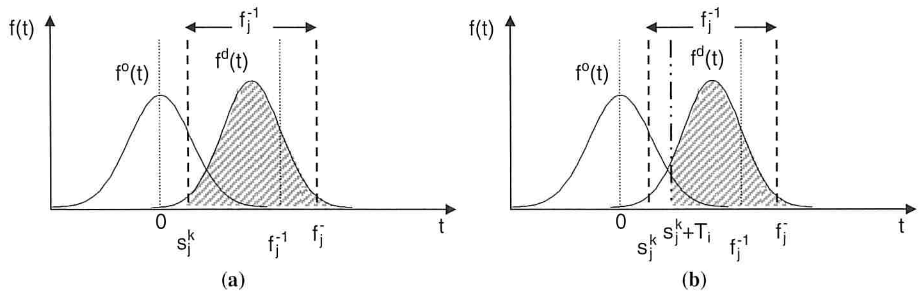


FIGURE 2 Probability of inbound vehicle on route *j* (*a*) arrives late and (*b*) arrives late after holding time T_i.

and next consecutive transfer terminals (i.e., delay propagation is not considered in this study). Thus, the relevant costs can be classified into two groups: costs incurred at the current transfer terminal k ($C_o^k + C_w^k + C_x^k$) and the downstream terminal k' ($C_w^{k'} + C_d^{k'} + C_x^{k'}$). These cost components are formulated in Equations 4 to 10.

$$C_{h,i}^k = \sum_{m\in M}\sum_{j\in J}\delta_i^k\delta_j^k \times \left(C_o^k + C_w^k + C_x^k + C_w^{k'} + C_d^{k'} + C_x^{k'}\right) \quad (3)$$

$$C_o^k = B_i T_i \quad (4)$$

If the decision is to hold ready vehicle i for time T_i, the additional vehicle operating cost at terminal k during the holding period can be formulated as Equation 4. B_i equals unit vehicle operating cost ($/vehicle-h).

$$C_w^k = \sum_{m\in M}\mu^m T_i\left[Q_i^{mk}h_i + \sum_{i'\in I, i'\neq i} q_{i'i}^{mk}h_i + q_i^{mk}\left(h_i + \frac{T_i}{2}\right)\right] + \sum_{m\in M}\sum_{j=1}^{j'-1}\mu^m q_{ji}^{mk}h_j \times \left[T_i - \int_{s_j^k}^{s_j^k+T_i} t\, f_j^d(t)\,dt\right] \quad (5)$$

Equation 5 expresses the additional dwell cost of existing loaded cargoes on the outbound route i. The loaded cargoes have three sources: originally loaded shipments (Q_i^{mk}) from inbound routes to terminal K, cargoes transferred from other ready vehicles ($q_{i'i}^{mk}$), and cargoes collected from the local center (q_i^{mk}) during the original scheduled headway (h_i) plus holding time (T_i). Thus, the first three terms in Equation 5 express the corresponding dwell costs of each source. The last term shows the expected dwell cost for those cargoes transferred from the late arrival vehicles during the holding time.

Equation 6 states the missed-connection costs of those vehicles arriving after holding time T_i. The incremental dwell time for these cargoes is the service headway of route i minus the expected late arrival time.

$$C_x^k = \sum_{m\in M}\sum_{j^*+1}^{j=J}\mu^m q_{ji}^{mk}h_j \times \left[h_i - \int_{s_j^k+T_i}^{h_j} t\, f_j^d(t)\,dt\right] \quad (6)$$

If it is assumed that the holding time would not affect the estimated link travel time, the dwell time of cargoes collected during the regular service headway will also increase T_i. Conversely, cargoes collected during the holding period would save some dwell time. Equation 7 specifies the overall cargo dwell cost incurred at the downstream terminal k' caused by the holding decision.

$$C_w^{k'} = \sum_{m\in M}\mu^m\left[T_i\left(q_i^{mk'}h_i\right) - \left(\frac{h_i - T_i}{2}\right)\left(q_i^{mk'}T_i\right)\right] = \sum_{m\in M}\mu^m q_i^{mk'}T_i\left(\frac{h_i + T_i}{2}\right) \quad (7)$$

The holding decision may also create some possible dispatching delay costs from route i to other routes ($C_{d1}^{k'}$) and from other routes to route i ($C_{d2}^{k'}$). These costs are formulated in Equations 8 to 10. The dispatching delay cost can be expressed by the joint probability distributions for vehicle arrival on any coordinated pair of routes (i, r). Two cases are considered in this cost component: (*a*) the feeder vehicle on route r arrives early, but the receiving one on route i is late and (*b*) both vehicles are late, but the feeder vehicle arrives before the receiving one. $f_d(t_i, t_r)$ denotes the joint probability of dispatching delay for transfer cargoes on some particular pair of routes. Thus, the dispatching delay costs from route i to other routes and those from other routes to route i at the downstream terminal k' are expressed in Equations 9 and 10, respectively.

$$C_d^{k'} = C_{d1}^{k'} + C_{d2}^{k'} \quad (8)$$

$$C_{d1}^{k'} = \sum_{m\in M}\sum_{\substack{r\in E\\ r\neq i}}\mu^m Q_{ir}^{mk'}\delta_i^{k'}\delta_r^{k'}f_d(t_i, t_r) \quad (9)$$

$$C_{d2}^{k'} = \sum_{m\in M}\sum_{\substack{r\in E\\ r\neq i}}\mu^m q_{ri}^{mk'}\delta_i^{k'}\delta_r^{k'}f_d(t_i, t_r) \quad (10)$$

Equations 11 to 13 state that the missed-connection cost ($C_x^{k'}$) occurs at downstream terminal k' due to the holding decisions for both directions ($C_{x1}^{k'}$: from route i to other routes and $C_{x2}^{k'}$: from other routes to route i). The missed-connection cost can be expressed by the joint probability distributions for vehicle arrival on any coordinated pair of routes (i, r). Two cases are considered: (*a*) the feeder vehicle on the route r arrives late, and the receiving one on route i is not late and (*b*) both vehicles are late, but the feeder vehicle arrives after the receiving one leaves. Then $f_x(t_i, t_r)$ denotes the joint probability of missed connections.

$$C_x^{k'} = C_{x1}^{k'} + C_{x2}^{k'} \quad (11)$$

$$C_{x1}^{k'} = \sum_{m\in M}\sum_{\substack{r\in E\\ r\neq i}}\mu^m Q_{ir}^{mk'}\delta_i^{k'}\delta_r^{k'}f_x(t_i, t_r) \quad (12)$$

$$C_{x2}^{k'} = \sum_{m\in M}\sum_{\substack{r\in E\\ r\neq i}}\mu^m q_{ri}^{mk'}\delta_i^{k'}\delta_r^{k'}f_x(t_i, t_r) \quad (13)$$

Equation 14 assumes that the required storage areas for the total missed-connection cargoes cannot exceed the available storage areas at transfer terminal k. ϵ equals unit cargo storage areas; A^k equals available storage areas at transfer terminal k. For the no-holding policy, j^* should be zero.

$$\epsilon\left(\sum_{m\in M}\sum_{j=j^*+1}^{j=J}\mu^m q_{ji}^{mk} h_j \delta_i^k \delta_j^k\right) \le A^k \tag{14}$$

Optimized Problem for Redistributing Missed-Connection Cargoes at Transfer Terminals

For those cargoes left over due to missed connections caused either by the no-holding decision or arrival after the ready vehicles have been dispatched, another problem is how to redistribute them. The mathematical model describing the redistributing plan is revised on the basis of the well-known location choice problem (*13*). To simplify the problem, the formulated model first considers cargo movements among the transfer terminals. After cargoes are shipped toward the latest transfer terminal, the same optimization model can be reapplied to distribute them toward the final destinations. It is assumed that the remaining space of each upcoming vehicle is known and given. Hence, the model is expressed as

$$\text{minimize } \omega = \sum_{m\in M}\sum_{\substack{k,l\in N\\k\ne l}}\sum_{p\in n_p} c_{kl}^{mp}\pi^p\alpha_{kl}^{mp}\beta^p + \sum_{p\in n_p}\lambda^p\beta^p \tag{15}$$

subject to

$$\sum_{\substack{k,l\in N\\k\ne l}}\sum_{p\in n_p}\pi^p\alpha_{kl}^{mp}\beta^p \ge d_{kl}^m \tag{16}$$

$$\sum_{m\in M}\sum_{\substack{k,l\in N\\k\ne l}}\alpha_{kl}^{mp}d_{kl}^m \le \pi^p \tag{17}$$

$$\sum_{m\in M}\sum_{\substack{k,l\in N\\k\ne l}}\sum_{p\in n_p}\alpha_{kl}^{mp} \le 1 \tag{18}$$

$$c_{kl}^{mp} = g\left(\mu_{kl(t=t_0)}^{mp}, \mu_{kl(t=t_e)}^{mp}\right) = \int_{t=t_e}^{t=t_0}\mu_{kl}^{mp}d_t \tag{19}$$

$$0 \le \alpha_{kl}^{mp} \le 1 \tag{20}$$

$$\beta^p \in \{0,1\} \tag{21}$$

where

ω = objective value of this optimization problem;
π^p = available space of the pth pickup vehicle;
α_{kl}^{mp} = fraction of the type m cargoes shipped from terminal k to terminal l by vehicle p;
d_{kl}^m = amount of type m cargoes shipped between transfer terminals k and l;
β^p = binary variable: if vehicle p is assigned to pick up missed-connection cargoes, then $\beta^p = 1$ (otherwise, $\beta^p = 0$);
λ^p = additional cost to use vehicle p;
n_p = set of pickup vehicle candidates; and
c_{kl}^{mp} = the expected travel time cost for the type m cargoes shipped from terminal k to terminal l through the pth vehicle.

The cost is defined as the changes of cargo time values during the current time ($t = t_0$) until the estimated shipping time ($t = t_e$). The objective function (Equation 15) consists of the sum of the total costs, including the vehicle activation cost. Equations 16–18 ensure that the total amount of missed-connection cargoes will be reassigned to the candidate pick-up vehicles and satisfy their remaining capacity limits. Equation 19 states the expected travel cost for the type m cargoes shipped from terminal k to terminal l. Equations 20 and 21 limit the range of the decision variables.

Solution Algorithm

Genetic algorithms (GAs) and sequential quadratic programming (SQP) are well-suited for solving such nonlinear programming problems with complex and nonlinear formulations (*14*). GAs can perform global search probabilistically and consider the evolution process after generations, and the algorithms can handle any kind of objective functions and constraints with a quite promising performance in approaching the global optimum (*15, 16*).

The SQP method is based on solving a series of sub-problems designed to minimize a quadratic model of the objective subject to a linearization of the constraints. If the problem is unconstrained, the method reduces to Newton's method for finding a point where the gradient of the objective vanishes. If there were some nonlinear constraints within the model, Lagrangian relaxation techniques could help maintain the linearization of those constraints (*17–19*).

Although both GAs and SQP have been widely applied in solving the nonlinear optimization problems, there are still some drawbacks to the use of these two approaches. Hybrid-based heuristic algorithms have become increasingly preferred because of their combinatorial advantages. In order to exploit the major advantages and improve the defects of the algorithms, Mansoornejad et al. have proposed some hybrid GA–SQP optimization techniques (*20*). Because these techniques still have room for improvement, an improved hybrid GA–SQP algorithm has been developed by Chen and Schonfeld (*21*). Detailed procedures for the proposed hybrid algorithm are specified in Figure 3.

In this multivariable nonlinear optimization problem, SQP can generate robust solutions based on given initial feasible solutions. However, the quality of the optimized solutions may be affected by different initial solutions. This problem can also be solved by a GA. The GA objective value can be improved by running additional generations, although with diminishing improvements. The proper number of generations that should be run depends on trade-offs between solution quality and the program running time. Thus, a hybrid GA–SQP algorithm is developed that can save some GA running time and provide better solutions.

In the hybrid approach, the authors use SQP (with any initial solution) to produce the starting solution to provide a reasonable threshold (i.e., the stopping criteria) for the following GA. The proposed algorithm then implements global search by GA, because the GA initially can converge very fast. The GA results can provide a fairly good initial solution for SQP, so the algorithm will switch to SQP again and repeat these steps until no further improvements are found.

MODEL APPLICATIONS AND ANALYTICAL RESULTS

Through this work, the authors attempt to optimize the dispatching decisions of ready outbound vehicles waiting for late inbound vehicles at an intermodal freight terminal. This study also provides flexibility

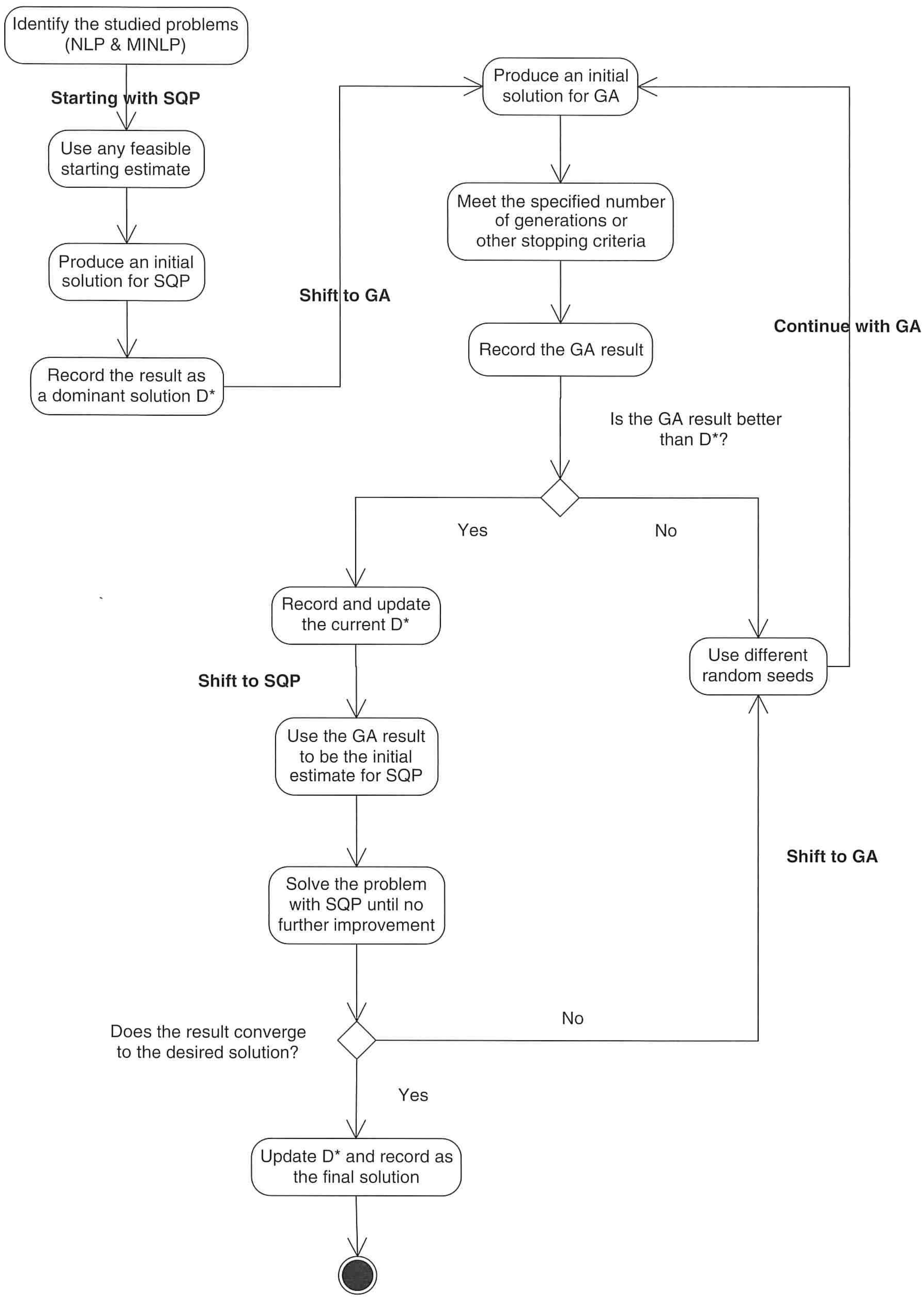


FIGURE 3 Procedures of proposed hybrid GA–SQP method.

in managing general and perishable cargoes with different dwell time value functions. The network configurations of two case studies are illustrated in Figures 4*a* and 4*b*.

Case 1. Single Commodity, Multimodes, Single Hub Operations

In Case 1, there are nine light-truck routes (Routes 1 to 9) and one heavy-truck route (Route 10) connecting to the terminal. To simplify the problem, the authors start from the single hub operation with symmetric demand between any pair of inbound and outbound routes. The carrying capacities of light and container trucks are 7,300 and 22,000 lb, respectively. The vehicle operating-cost function is expressed as $a + b * c$ where a represents the fixed cost (\$/h), b represents the variable cost (\$/lb-h), and c is the capacity for the vehicle. In this case, a equals 100 (light) and 200 (heavy), and b equals 0.03 (*22*). The unit cargo dwell cost is \$0.2/lb-h (*23*). Unit cargo loading and processing time are set as 0.03 and 0.05 min/lb, respectively.

As shown in Table 1, the common headway coordination method has the same results as the integer–ratio approach. When comparing the values for coordinated and uncoordinated objective functions,

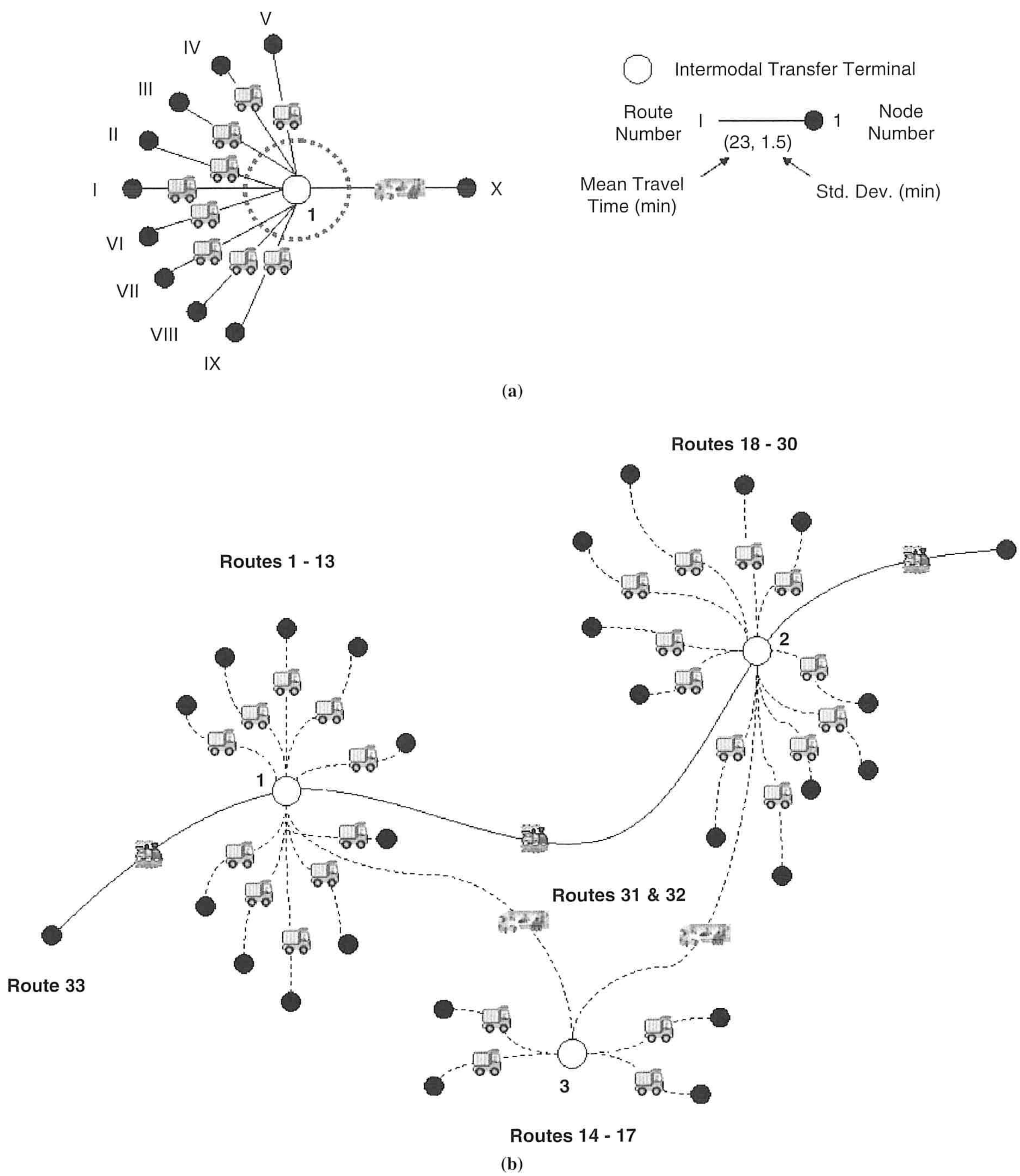


FIGURE 4 Network configurations for (*a*) Case 1 and (*b*) Case 2.

TABLE 1 Overall Results of Different Policies in Case 1

Factor	Uncoordinated Organized Headways (h/veh)	Uncoordinated Frequency (veh)	Coordinated (GA) Organized Headways (h/veh)	Coordinated (GA) Frequency (veh)	Coordinated (GA–SQP) Organized Headways (h/veh)	Coordinated (GA–SQP) Frequency (veh)
Route						
1	1.3365	0.7482	0.9661	1.0351	0.9670	1.0341
2	1.2953	0.7720	0.9661	1.0351	0.9670	1.0341
3	1.2175	0.8214	0.9661	1.0351	0.9670	1.0341
4	1.3256	0.7544	0.9661	1.0351	0.9670	1.0341
5	1.1789	0.8482	0.9661	1.0351	0.9670	1.0341
6	1.3687	0.7306	0.9661	1.0351	0.9670	1.0341
7	1.3243	0.7551	0.9661	1.0351	0.9670	1.0341
8	1.2934	0.7732	0.9661	1.0351	0.9670	1.0341
9	1.3619	0.7343	0.9661	1.0351	0.9670	1.0341
10	0.9660	1.0352	0.9661	1.0351	0.9670	1.0341
Slack Time						
S_1^1, S_2^1	—		0.0326, 0.0756		0.0170, 0.0557	
S_3^1, S_4^1	—		0.0321, 0.1064		0.0300, 0.0170	
S_5^1, S_6^1	—		0.0209, 0.0217		0.0229, 0.0466	
S_7^1, S_8^1	—		0.0203, 0.0793		0.0175, 0.0246	
S_9^1, S_{10}^1	—		0.0535, 0.0500		0.0558, 0.0500	
Costs ($/h)						
Operating cost	10,382		12,496		12,485	
Dwell cost	5,216		4,444		4,447	
Loading–unloading	10		9		9	
Cargo processing	9		7		7	
Nontransfer cost	15,617		16,956		16,948	
Intercycle	—		0		0	
Slack time	—		661		509	
Misconnection	—		1,724		1,958	
Dispatching delay	—		442		328	
Transfer cost	5,216		2,827		2,795	
Total system cost	20,833		19,783		19,743	

NOTE: — = not applicable.

it is observed that the coordinated approaches are better than the uncoordinated system, especially for transfer costs. It is clear that higher service frequencies lead to higher operating cost and lower cargo dwell, loading, unloading, processing time, and costs associated with lower load factors. Both GA and hybrid GA–SQP applications can reach similar optimized results (i.e., the difference between total system costs is only 0.2%).

Testing for Real-Time Dispatching Applications (Case 1)

A small 10-route network with a single transfer terminal and homogenous cargoes is considered in the following dispatching analysis. Based on the above coordinated results, these 10 routes are synchronized at Transfer Terminal 1, assuming that inbound vehicles on Routes 1, 3, 5, 6, 8, and 9 have estimated delays, while the vehicle on Route 10 is ready to be dispatched. The delay information is shown in Table 2.

TABLE 2 Inbound Routes Delay Information for Case 1

Inbound Route	Outbound Route 10 (lb/h)	Route Travel Time (min) Mean	Route Travel Time (min) Std. Dev.	Delay Information (min) Mean	Delay Information (min) Std. Dev.
1	2,450	82	8.0	14.5	0.25
2	3,150	99	9.5	—	—
3	1,550	43	3.5	6.5	0.25
4	3,250	107	10.0	—	—
5	1,500	39	3.5	12.0	0.20
6	2,250	79	7.5	16.0	0.35
7	3,500	115	10.5	—	—
8	3,000	94	9.0	7.5	0.35
9	2,100	73	6.5	22.5	0.20

NOTE: Std. dev. = standard deviation.

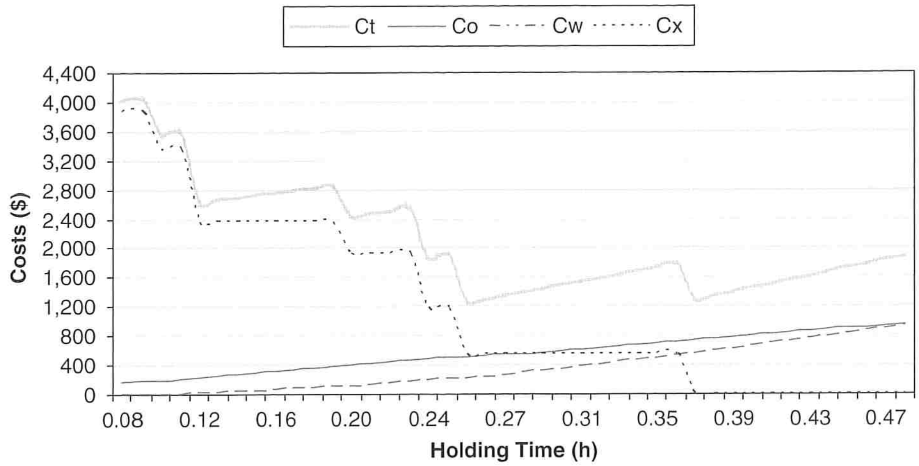


FIGURE 5 Costs with different holding time of Route 10 in Case 1.

As shown in Figure 5, vehicle operation cost (C_o) and cargo dwell cost (C_w) increase while increasing the holding time of the ready vehicle. Conversely, the missed-connection cost (C_x) decreases because more late inbound vehicles arrive during the longer holding period. At the end, the missed-connection cost would approach zero, which means all delayed cargoes are being picked up. Because there is only one transfer terminal in Case 1, costs incurred at downstream terminals are not considered. The optimized holding time solved with the hybrid GA–SQP algorithm is 0.255 (h), which indicates that the ready vehicle should wait until the fifth late vehicle (from Route 6) arrives.

Case 2. Multiple Commodities, Multiple Modes, and Multiple Hubs with Loop in Network

Thirty light-truck routes (Routes 1–30), two container-truck routes (Routes 31–32), and one rail route (Route 33) are analyzed in Case 2. As shown in Figure 4*b*, the three transfer terminals are arrayed in a loop. Coordination at one transfer terminal will affect the other transfer hubs in the loop. Only considering the coordination of a pair of transfer terminals may lead to conflicts of coordination of another pair of terminals. More transfer terminals within the loop and more loops within the entire networks would increase the complexity of the studied problem.

The vehicle capacities of light truck, container truck, and rail train including six container stack railcars are 22,000, 44,000, and 1,017,000 pounds, respectively. In this case, $a = 200$ (heavy), 250 (container), and 300 (rail). Two types of shipments with different unit time values are \$0.25*exp($-t$)/lb–h and \$0.1/lb–h. All other settings are as in Case 1.

Under uncoordinated operations, 30 light-truck routes tend to be served with smaller headways than those of the two container-truck routes and the rail route. The integer–ratio schedule coordination outperforms the uncoordinated and the common-headway coordinated operations for the given input information. The common service method is inefficient and undesirable in this case because the demands or travel lengths of different routes vary too much. ϵ represents the base cycle value for coordination approaches. The optimized headways are ϵ (light truck), 2ϵ (container truck), and 5ϵ (rail) where $\epsilon = 2.033$ (h). Detailed results are provided by Chen and Schonfeld (*21*).

Testing for Real-Time Dispatching Applications (Case 2)

In this multi-hub operation problem, costs at downstream terminal k' are considered. For transfer terminal l, it is assumed that inbound vehicles on Routes 1, 2, 3, 5, 6, 8, 10, and 13 have estimated delays, while the vehicles on Routes 31 and 33 are ready to be dispatched. Table 3 provides some O-D data and delay information. In Figure 6*a*, vehicle operation cost (C_o^k) and cargo dwell costs (C_w^k and $C_w^{k'}$) increase as the holding time increases. Similar to Case 1, the missed-connection cost (C_x^k) decreases because fewer cargoes miss their connections during the longer holding period. However, missed-connection ($C_x^{k'}$) and dispatching delay ($C_d^{k'}$) costs are also incurred at the downstream terminal. Steps and local optima in Figure 6*a* are caused by the arrival of additional inbound vehicles and the resulting successful connections. The overall trade-off results are illustrated by the total cost (C_t) curve.

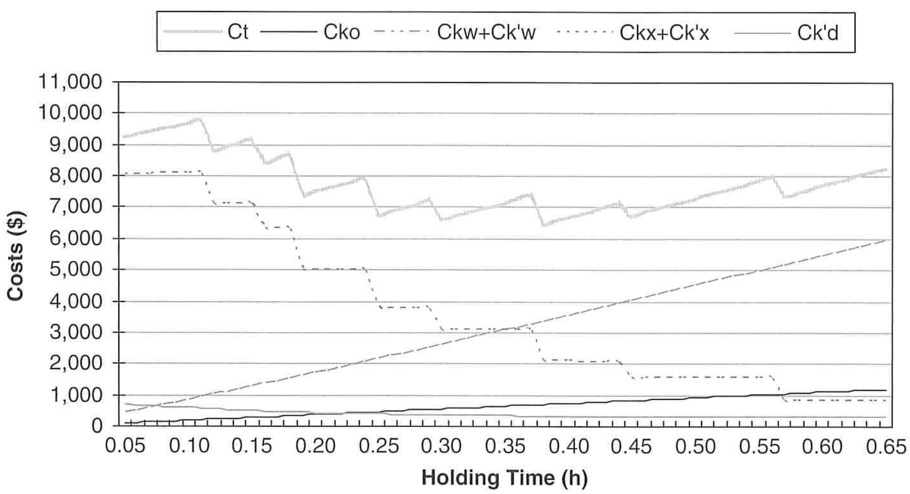
The optimized holding time (T_{31}) solved with the hybrid GA–SQP algorithm is 22.21 (min), which indicates that the ready outbound container-truck on Route 31 should wait until the sixth late light truck (from Route 1) arrives. In Figure 6*b*, the trends of all cost terms are similar to those in previous cases. The optimized holding time (T_{33}) is 26.874 (min), which means that the ready outbound rail train on Route 33 should wait until the seventh late light truck (from Route 6) arrives.

Testing for Redistributing Applications (Case 2)

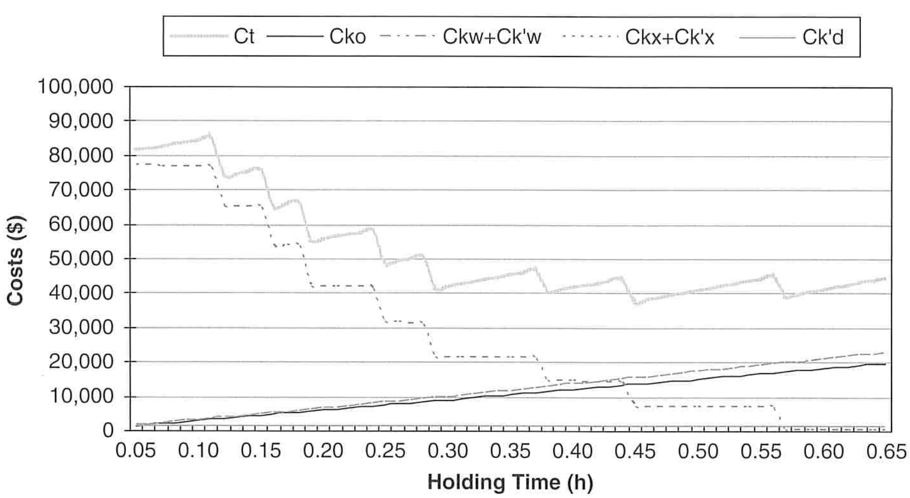
According to the real-time dispatching decisions, some missed-transfer cargoes are left over at Terminal 1, as shown in Table 4. The amounts of missed-connection cargoes are derived from the O-D information and the service headway of the light-truck routes, assuming some candidate pickup vehicles, including one rail train ($p = 1$) and three container trucks ($p = 2$ to 4) can transport those cargoes from Terminal 1 to Terminals 2 and 3. The train will arrive in

TABLE 3 Inbound Routes Delay Information for Case 2

Inbound Route (from)	Route Travel Time (min)		(To) Outbound Truck Route 31 (lb/h)		(To) Outbound Rail Route 33 (lb/h)		Delay Information (min)	
	Mean	Std. Dev.	$m = 1$	$m = 2$	$m = 1$	$m = 2$	Mean	Std. Dev.
1	97	8.6	503	1,081	1,311	2,817	23	0.4
2	60	5.3	551	1,185	1,937	4,166	12	0.3
3	68	7.4	302	649	1,674	3,598	18	0.35
4	104	10.5	189	406	1,752	3,767	—	—
5	53	5.5	303	652	1,714	3,688	10	0.25
6	93	8.8	243	523	1,395	3,000	27.5	0.45
7	85	9.1	382	821	2,145	4,612	—	—
8	64	7.2	520	1,118	1,688	3,630	15.5	0.3
9	83	7.7	378	812	1,356	2,915	—	—
10	41	4.5	366	786	1,696	3,647	7.5	0.25
11	32	3.6	524	1,127	2,221	4,775	—	—
12	56	4.8	381	820	2,036	4,378	—	—
13	99	10.1	380	817	1,289	2,772	35	0.5



(a)



(b)

FIGURE 6 Costs with different holding time of (*a*) Route 31 and (*b*) Route 33 in Case 2.

TABLE 4 Redistribution Results in Case 2

Cargoes Left at Terminal 1	Destination Terminal 2 (lb)		Destination Terminal 3 (lb)	
	$m = 1$	$m = 2$	$m = 1$	$m = 2$
6	—	—	494	1,063
13	2,621	5,636	773	1,661

TABLE 5 Optimized Redistribution Results in Case 2

$p = 1$	—	5,636	—	—
$p = 2$	983	—	1,267	—
$p = 3$	1,638	—	—	762
$p = 4$	—	—	—	1,982

10.165 h, and three trucks will arrive in 4.066, 8.132, and 12.198 h, respectively (i.e., based on the original optimized and coordinated schedules). The candidate delivery vehicles for redistribution are p = 1 (50,000 lbs.), p = 2 (2,250 lbs.), p = 3 (2,400 lbs.), and p = 4 (2,000 lbs.). In general, most of the cargoes are reassigned to candidate vehicles on the basis of their shortest path (e.g., Terminal 1 to 3 or Terminal 1 to 2). However, certain cargoes with higher time value (m = 1) are reassigned to a farther path (i.e., Terminal 1 to 3 to 2) so as to minimize total shipping time (i.e., longer travel time but much shorter dwell time). The results may vary based on different cargo time values.

Testing with Different Cargo Time Values (Case 2)

Unit cargo time value functions describe the characteristics of the shipments, which also imply the priorities of cargoes. To observe how decisions may be affected by cargo time values, a sensitivity analysis is described. The parameter settings in Figure 6*b* (Type 1: \$0.25 * exp($-t$)/lb-h and type 2: \$0.1/lb-h) duplicate the base case. Two different time value settings are tested (high settings: \$0.4 * exp($-t$)/lb-h and \$0.2/lb-h; low settings: \$0.08 * exp($-t$)/lb-h and \$0.03/lb-h).

As previously noted, the optimized holding time (T_{33}) of the base case is 26.874 (min), which indicates the ready vehicle should wait until the seventh late vehicle arrives. If the unit cargo time values are relatively low, the optimized holding time becomes 17.502 (min), which means the ready vehicle leaves as soon as the fifth late vehicle arrives (and connects). At the higher time value settings, the holding time becomes 34.008 (min), which means the ready vehicle should wait for all delayed vehicles to avoid high missed-connection costs. Detailed results are illustrated in Figure 7.

CONCLUSIONS

In this study, the authors consider several logistic problems arising when routine service disruptions occur. The adjustments needed for the original schedules to adapt to the changing environment and to get back on schedule fast enough are the main decisions optimized in this work. A real-time dispatching control model can help operators determine through an optimization process whether the ready outbound vehicles should be dispatched immediately or held for others.

The model is designed to consider transfers among or within various modes, as long as the mode and route characteristics are specified. Most input parameters in the numerical section are based on the authors' literature review and information gathered from websites. Although these values may not be very typical, the model can use whatever inputs its users consider most applicable. The usefulness of the numerical results can be increased by further improving the proposed real-time control model from routine disruption cases to major disruptions.

As shown in Case 1, the authors mainly attempt to determine the best dispatching decisions by minimizing net system costs, starting by assuming a constant time value of cargoes shipped through a single hub. When comparing the total costs with different holding time periods, the authors quantify how a longer holding time would yield higher vehicle operation cost and cargo dwell cost but lower missed-connection cost.

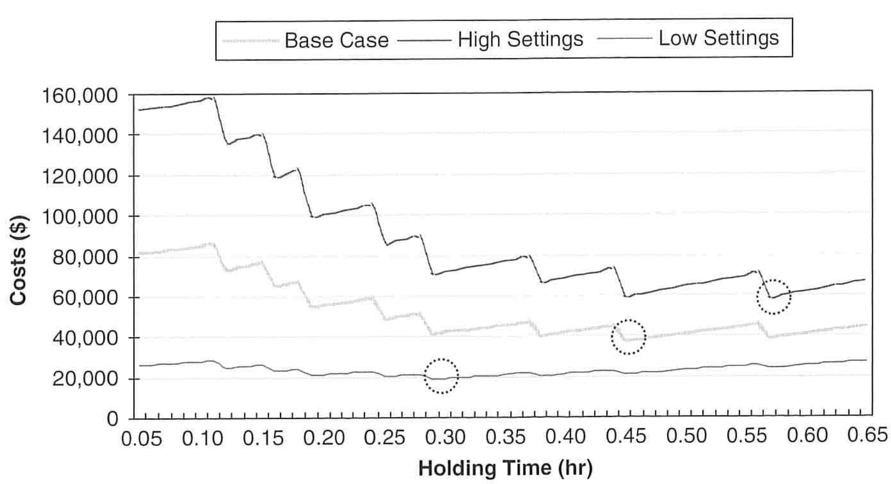


FIGURE 7 Sensitivity analyses with different time value settings in Case 2.

In Case 2, multiple hubs forming a loop and a multi-commodity problem with nonlinear time value functions is explored. Although increased holding time could reduce the missed-connection cargoes at the current terminal, it may also incur higher costs of extra cargo dwell time, dispatching delay, and missed connection at the downstream terminal. During the post-dispatching phase, the cargoes left over because of missed connection can be redistributed to other delivery vehicles on the basis of their remaining spaces and priorities of cargoes. Additionally, a sensitivity analysis shows that the ready outbound vehicle should wait longer to reduce the missed transfers and higher missed-connection costs as the cargo time value increases.

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On the History of the Pony Express and Extending Its Operation into the Telegraph Era

Wayne D. Cottrell

The Pony Express was a horseback mail delivery endeavor that lasted from April 1860 until October 1861. The route extended from Saint Joseph, Missouri, to Sacramento, California, and then on to San Francisco, California, by boat. With letters sealed in a mail pouch, riders covered the 1,966-mi route in no more than 10 days. The fast pace was sustained by exchanging horses every 10 mi and riders every 75 to 100 mi. The Pony Express ceased operations amid huge financial losses and the completion of the transcontinental telegraph. This study reviews its history and asks whether a healthy, solvent Pony Express could have survived competition from the telegraph until completion of the transcontinental railroad in 1869. A trinomial logit model compares the probabilities of choosing between standard mail, Pony Express, and telegraph. Market shares of 96.5% for standard mail, 2% for telegraph, and 1.4% for Pony Express are estimated on the basis of their 1861 prices and other historical information. Lowering the Pony Express rate from \$1 to \$0.30 per ½ oz would have doubled the market share, and increased the annual number of letters from 104,000 to 208,000. But the \$62,400 earnings would have failed to meet the operating costs, and raising the rate would have meant a loss of customers. The Pony Express, therefore, would not have withstood competition from the telegraph. It would have had to shift its service market to package delivery, probably early on, to have sustained the operation. The Pony Express is nonetheless considered responsible for advancing transportation and communication in the United States.

Although the business lasted for only 18 months (April 1860–October 1861), the Pony Express remains an enduring legacy of American enterprise and determination. It was a mail-delivery-by horseback venture—a risky undertaking that ultimately failed. The Pony Express, however, is considered to be responsible for stimulating the completion of the transcontinental telegraph, and perhaps even the transcontinental railroad, which was completed in 1869. Examining the former, the Pony Express bridged the gap between the completed portions of the telegraph between California and Nebraska (and then Wyoming, Utah, and Nevada) during construction of the transcontinental line—maintaining communication and keeping hopes up (*1*). From an examination of the transcontinental railroad, the preferred alignment was clear once the Pony Express demonstrated the viability of the central route across Nevada and into California (*2*). The central route became the primary path for the telegraph, the railroad, and eventually the Lincoln Highway (America's first transcontinental road). The Pony Express also served an important role in maintaining communications between California and the eastern United States. This was particularly critical in 1861, when southern states were in the process of seceding from the Union. California may have been inclined to secede as well had it not been for the swift lines of communication that kept decision makers informed, thereby fending off the state's isolation. For example, President Abraham Lincoln's inaugural address of March 3, 1861, was published in San Francisco, California, newspapers on March 17. The rapid transmission of the message revived the sagging spirits of Union sympathizers and energized the loyalists (*3*).

A substantial amount of literature covers the heroic undertaking of the Pony Express. It is well-known that the Pony Express operated until 2 days after the completion of the transcontinental telegraph. Despite the glamour associated with the visionaries, political officials, owners, and riders of the Pony Express (as well as the romanticized route over plains, mountains, and deserts), the endeavor accumulated huge financial losses. Research has produced lists of the riders, the routes they traveled, special feats of long-distance travel, and their activities after the demise of the Pony Express. There has not been a study, however, on the extent to which a healthy Pony Express might have competed with the telegraph during the 1860s. That is, could a financially solvent Pony Express have survived until the completion of the transcontinental railroad in 1869? An analysis of these elements is critical to gain an understanding of how the Pony Express could have survived beyond its 18-month lifetime and whether it could have competed with improving modes of transportation and communication. It is also useful to understand a 19th century competition between the Pony Express and telegraph in terms of a more modern-day competition between, say, express package delivery and electronic communication such as e-mail. To contribute to an improved understanding of the enterprise's sustainability, this paper reviews the Pony Express' colorful history, and develops some simple discrete choice models of mid–19th century mail demand in the United States.

BACKGROUND

As of 1850, the United States consisted of 31 states, four organized territories, and two unorganized regions (*4*), the latter of which were set aside by the Indian Intercourse Act of 1834, and later treaties for relocated Native American tribes (*5*). Most of the states were east of the Mississippi River; all of the territories, along with just six states, were west of the Mississippi. The newest state, California, was sepa-

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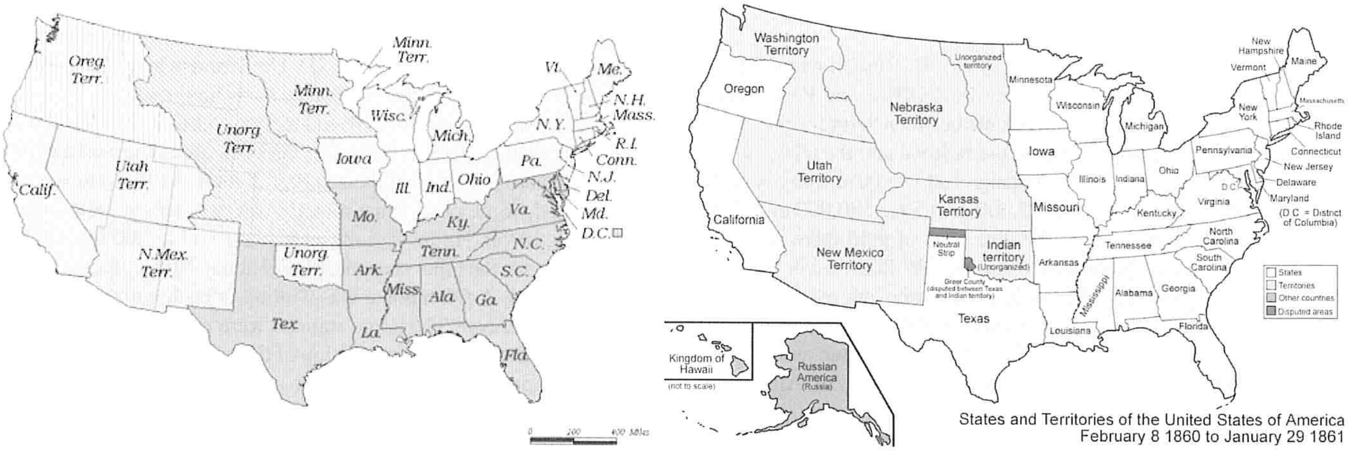

(a) (b)

FIGURE 1 United States in (a) 1850 and (b) 1860.

rated from the other 30 by the territories (*6, 7*) (Figure 1). America's frontier line followed a sinewy path that snaked its way north–south through the states located immediately west of the Mississippi River (Iowa, Missouri, Arkansas, and Louisiana) (*8*). West of the frontier line were rugged mountains and harsh deserts, the Continental Divide, purportedly hostile Native Americans, "stampeding" buffalo, gunplay, and general lawlessness. The U.S. population was 23.2 million, of which 400,000 (1.7%) lived in the organized frontier, while up to another 280,000 lived in the Indian Territory. California had a rapidly growing population of 92,600, representing 15% to 20% of the frontier (*9*).

By 1860, Minnesota and Oregon had achieved statehood, and portions of the West's unorganized territory had been organized into the Kansas and Nebraska Territories. The U.S. population was 31.4 million, up 35.4% from 1850's population. The population of the frontier was about 1.1 million, with California home to about one-third of the growing western United States (*10*). Keeping California connected to and informed about the rest of the Union was a challenge. With no roads, motor vehicles, railroads, telephones, telegraph, or interior waterways connecting the eastern with the western United States, communication was limited. Mail was the only organized form of long-distance communication. The U.S. Post Office (USPO), established in 1789, extended the delivery of mail westward from the eastern states during the 19th century as the nation expanded. To get to California, rather than cross the potentially hostile frontier, the USPO contracted with two steamship companies to transport mail from New York to California via the isthmus of Panama (*11*). The entire journey "could be accomplished—with a dose of luck—in eight weeks or less" (*12*). Despite the lengthy journey, it represented a great improvement on the six-month travel time from New York to San Francisco, California, via Cape Horn at the tip of South America.

Despite the USPO efforts to deliver mail to California in a timely manner, the state was still isolated. For example, California became a state September 9, 1850, but residents of Los Angeles, California, did not learn of it until six weeks later (*11*). California residents also complained about the high costs of mail delivery, at \$0.12 to \$0.80 per oz (\$0.04 to \$0.028 per gm), and the infrequent, semimonthly ships (*13*). To move the mail more rapidly, there was no choice but to go over land. Erratic overland mail service to California was provided by the U.S. military starting in 1848, followed by a few entrepreneurial efforts. Some of the latter performed as little as one traverse of the frontier before terminating operations. In 1851, Absalom Woodward and George Chorpenning received a government contract to carry mail by stagecoach from Salt Lake City, Utah, to California, also in 30 days. After a rough first winter, in which several horses froze to death, the pair decided to use a northerly emigrant route to Sacramento, California, during the summer and a southerly route to Los Angeles during the winter. The total scheduled time from Missouri to California was 60 days—no faster than the New York to California steamships. Starting in 1854, the Chorpenning enterprise switched to the southerly Mormon route exclusively, with the mail carried on horseback or pack mules. A new government contract reduced the scheduled one-way time to 28 days, but Chorpenning's horses covered the Utah–Los Angeles route in as little as 20 days (*14*). By 1858, there were several mail delivery options, as shown in Table 1. The two steamship lines both featured an overland segment, with transport by canoe or mule across Panama's isthmus and, later, by railroad.

TABLE 1 Overland and Water Mail Routes to California, 1858

Eastern Endpoint	Western Endpoint	Route	Mode	Frequency	Distance (*15*) (mi)	Travel Time (*15*) (days)
Independence, Mo.	Placerville, Calif.	Central[a]	Stagecoach	Weekly	2,005	32–38
Kansas City, Mo.	Stockton, Calif.	via Santa Fe, N.Mex.	Wagon	Monthly	2,640	54–60
Saint Louis, Mo.	San Francisco	via El Paso, Tex.	Stagecoach	Semiweekly	2,800	25
San Antonio, Tex.	San Diego, Calif.	via El Paso	Stagecoach	Semimonthly	1,475	22–26
New Orleans, La.	San Francisco	via Acapulco, Mexico	Steamship	Semimonthly	3,070	15–18
New York City	San Francisco	via Panama	Steamship	Semimonthly	5,255	30

[a]Originally, the route followed the more northerly Humboldt River; the switch to the Central Route was made after 3 months.

ESTABLISHMENT OF PONY EXPRESS

Freight transport company owner William H. Russell campaigned vigorously for backing by the Senate Post Office and Post Roads Committee for an overland express route between Saint Joseph, Missouri (the western terminus of both the railroad and the telegraph at the time), and California. The campaign followed California's population surge of the 1850s (from 92,600 in 1850 to 380,000 in 1860), which had been stimulated by the discovery of gold there in 1849. Russell had, at least, the support of Senator William Gwin of California, who had introduced a bill in 1855 proposing establishment of a weekly letter express service between Saint Louis, Missouri, and San Francisco. The bill stalled in the Senate Committee on Military Affairs, however, never making it to the Senate floor (*16*). After conversations with Senator Gwin, Russell was further energized about the need for improved mail connections to points west (*17*). There were growing concerns that California would side with the South as pro-slavery versus antislavery tensions continued to mount. There was even some concern that California would break away from the Union altogether, becoming an independent Pacific republic. Thus, and despite Gwin being a southern states sympathizer, it was evident that communication links between California and the eastern United States needed to be strengthened (*18*).

In November 1859, Russell teamed with Alexander Majors and William B. Waddell to form the Central Overland California and Pike's Peak Express Company in the Kansas Territory. The new corporation absorbed the Leavenworth and Pike's Peak Express Company (a stagecoach service) along with several other stage routes (*19*). Despite losses from the Leavenworth and Pike's Peak partnership that had been established in 1859 with Russell's involvement, he, along with Majors and Waddell, proceeded to invest in the Pony Express venture (*20*). Their investment was based in part on the prospects for future financial support from the federal government. The first step was to acquire and build relay stations along the central route that had been pioneered by George Chorpenning, a leader in establishing and operating stagecoach lines in the West. Abandoned stations from Chorpenning's central route stagecoach line already existed. The central route, starting in Saint Joseph, passed through Kansas, Nebraska, Colorado, Wyoming, Utah, Nevada, and California, for a total distance of 1,966 mi (Figure 2) (*21, 22*). Government support might be generated with proof of the viability of the central route.

Although the route ended in Sacramento, California, the mail was carried from there to San Francisco via boat, along the Sacramento River and across the San Francisco Bay. A total of 119 stations were established, some new, some already in existence, to serve overland stage travel. Home stations were placed 75 to 100 mi (120 to 160 km) apart; the other stations, placed about 10 mi (16 km) apart, were outposts. A fresh horse was waiting at each outpost for both directions of travel. The home stations were rider exchange points (*18*). To assist with the organization of the enterprise, the route was classified into five divisions; each division superintendent was responsible for several hundred mi of the route.

To prepare for the inauguration of the service on April 3, 1860, numerous resources needed to be procured and positioned, including riders, station keepers, stock tenders, station and outpost supplies, mochilas (mail pouches), saddles, firearms, and horses. A total of 80 riders and 500 horses were employed at start-up. Firearms were provided for protection, particularly for riders west of Salt Lake City. There was also a cabinet of executives, including several superintendents and officers (*23*). All of the resources and infrastructure were hastily readied over a three-month period. In addition to the cabinet, an executive committee with William H. Russell as president was named. Offices were established in San Francisco; Saint Joseph; Saint Louis; Chicago, Illinois; New York City; and Washington, D.C. (*24*).

INVESTMENT IN PONY EXPRESS

A total of $20,000 (U.S., 1860; equivalent to about $532,000 in 2010) was initially invested in supplies for the stations and outposts. The supplies did not last, particularly along the arid, barren section between the California–Nevada border and Salt Lake City, Utah. Nearly every item, including wood, had to be hauled in from great

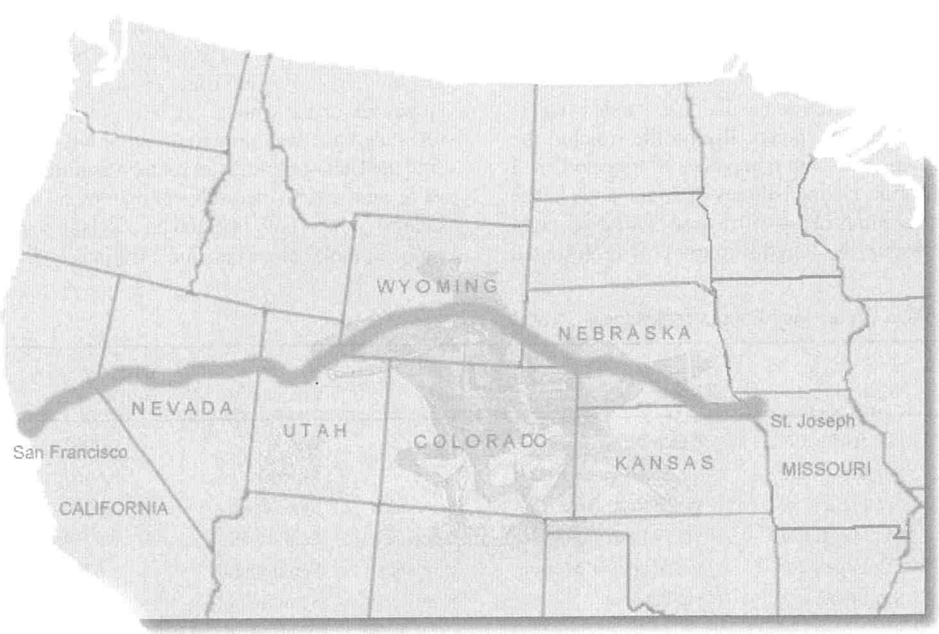

FIGURE 2 Pony Express route.

distances to supply this segment. By the end of the Pony Express, \$100,000 had been spent on equipment. The enterprise sought fast horses exclusively—mustangs and Cayuse—which were purchased for \$175 to \$200 each. A total of \$87,000 was initially invested in horses (*20*). Additional horses were purchased later, as the Pony Express matured and as the organizers acquired an improved sense of the resources needed.

The federal government was never as enthusiastic about the Pony Express as the entrepreneurs, the newspapers, the many business clients who used the service, and those who were involved in the operations. A bill requesting an annual \$1 million subsidy made it to Congress in 1860 but lacked support. Although Russell, Majors, and Waddell eventually received a \$475,000 subsidy from Congress in 1861, it was for stagecoach operations along the central route (*20*). The notion of an enclosed, protected stagecoach was endorsed, but not that of a vulnerable, solo rider on horseback. In fact, as early as 1785, the U.S. Congress preferred stagecoach over horseback proposals for mail delivery; horseback riding was occasionally referred to as an "inferior mode," while a stagecoach was referred to as a "higher mode of service" (*25*). Yet, the pace of the stagecoach was such that the mail took twice as long to deliver as the Pony Express. Data do not seem to exist on solo rider vulnerabilities—or even on whether they were any more subject to ambush than stagecoaches. Wells Fargo, which favored stagecoaches—possibly in keeping with the congressional preference—assumed partial ownership of the Pony Express in early 1861 (*26*). It is unknown to what extent there was an internal conflict between pony- and stagecoach-oriented mail delivery services, or how much effort was put into sustaining the former.

PONY EXPRESS OPERATIONS

Running the Pony Express was costly. The highest-paid employees were the executives, but the riders were also well-paid. Secretary Russell earned \$150, while Superintendent Benjamin Ficklin earned between \$250 and \$300 per month. Each of the division superintendents received \$90 per month. Riders were paid an average of \$50 per month, plus room and board, although some articles report payments of \$100 per month. Also, bonuses were given to the riders for extraordinary feats, such as safely transporting the mail through an insurgence of hostile Native Americans or doing double-duty for a sick, frightened, or accosted rider. At its peak of operation, which occurred several months after start-up and fluctuated over time, there were 190 stations, 80 riders, 400 station attendants and assistants, and 420 horses in use (*12*).

The Pony Express ceased to operate on October 26, 1861, just 2 days after the transcontinental telegraph was completed. The telegraph eliminated the need to transport most of the letters between California and points east, although horse transport was still needed to deliver packages and to deliver mail to remote areas of the West that were not on a telegraph line. Detailed records of Pony Express accounting during its 18-month existence do not exist, unfortunately, despite painstaking research by a number of investigators (*27*). Cumulative cost estimates, however, were as follows (*12*):

- Equipment and supplies: \$100,000;
- Executive, rider, and station attendant salaries: \$480,000;
- Paiute War: \$75,000;
- Other equipment, horses, and horse maintenance: \$45,000; and
- Total: \$700,000.

While the operating costs of the Pony Express were high, the price to users was also high. The initial cost for mailing a letter was up to \$5 per half-ounce. Mail traveling between San Francisco and Salt Lake City (less than half the length of the entire route) cost \$3 per ½ oz. By comparison, the cost of mailing a letter in the United States in 2010 was \$0.44 for up to a full ounce. Near the end of the Pony Express venture 18 months later, the price had dropped to \$1 per ½ oz. By this time, Wells Fargo and Company had assumed management duties and were franking letters with the new postage (*26*). Researchers disagree on the total receipts during the 18-month operation; one source estimated as little as \$90,000, while another estimated as much as \$500,000, although all agreed that the enterprise lost about \$200,000 (*28*). Adding to the expenses was the Paiute War—also referred to as the Pyramid Lake Indian War, the Pyramid Lake Uprising, and the Washoe Indian War. Although a Paiute attack on the Williams Pony Express Station in Nevada instigated the war, three decades of wanton violence against Native Americans in Nevada preceded the event. Historians disagree on the impacts of the war on the Pony Express, but the consensus is that they were significant and lasting. Service was disrupted for 3 weeks to 2 months, and there were frequent skirmishes with Paiutes for many months afterward. Several Pony Express stations were destroyed, usually by fire, and a number of station keepers and outpost attendants were murdered. One rider was killed. The reputed cost of the war to the Pony Express enterprise was \$75,000. The greater cost to the enterprise, however, was the perceived vulnerability of the service. The federal government took note of this, and the war-related delay was probably a factor in the failure of Russell, Majors, and Waddell to secure a subsidy (*20*).

TELEGRAPH REPLACES PONY EXPRESS

An additional factor in the Pony Express' failure to obtain government backing was the concurrent development of the telegraph. The Pony Express' initial runs, in which mail was being transported from St. Joseph to San Francisco in 10 days or fewer, spurred interest in an even faster means of conveying information. Just over 2 months after the inauguration of the Pony Express, Congress passed a bill providing \$40,000 annually for 10 years to the USPO for development of the telegraph. The telegraph enabled the rapid transmission of messages through the use of Morse code to create telegrams—cryptic but decoded messages of just a few words (somewhat similar to today's text messages). Telegraph lines were already connecting San Francisco with Carson City, Nevada, and were extending from Fort Kearney, Nebraska, to points east. The long gap between Carson City and Fort Kearney (1,270 mi or 2,040 km) was to be filled using the new government funds. The transcontinental telegraph lines were completed October 24, 1861, and the Pony Express stopped running 2 days later (*29*). Ridge (*30*) has argued that the Pony Express was not "doomed" outright by the telegraph, however, because of Russell's twofold purposes of proving that the central route was viable and winning a federal subsidy that would have otherwise been destined for John Butterfield's Overland Mail Company.

SPECULATING ON COMPETITION WITH TELEGRAPH

With the completion of the transcontinental telegraph in 1861, the coast-to-coast message transmission time was reduced from days to seconds, and the Pony Express was no longer the fastest way to deliver a message (*6*). The price of the telegraph was exorbitant, however. It was \$5 for a 10-word message from San Francisco to Saint Louis, and \$6 from San Francisco to New York (*31*). Additional words were \$0.45 each to Saint Louis, and \$0.75 each to New York. Thus, the equivalent of a one-page letter, at about 300 words, could cost the sender \$223.50 to transmit coast to coast. The Pony Express

was substantially less expensive for long messages and was also suitable for newspaper delivery.

Had the Pony Express endured and survived competition from the telegraph, the completion of the transcontinental railroad in May 1869 would have certainly signified the end of the enterprise. So, with an improved business model, could the Pony Express have lasted an additional 7½ years? The 1860s were a period of continued growth and expansion in the western United States amid turmoil in the eastern and southern United States. California continued to grow from a population of 380,000 in 1860 to 560,200 in 1870 (*32*), but the growth was not as dramatic as during the 1850s. This was partially because of the Civil War, which stymied progress nationwide between 1861 and 1865.

For mail delivery, a turnover in the USPO's administration resulted in the termination of effectively all of the 1850s mail routes to California. All of the lines, listed in Table 1, suffered huge financial losses. During the 1860s until the transcontinental railroad was completed, the USPO, with various forms of federal support, contracted with a number of providers to carry mail to the West. The modes included overland stagecoaches for long (e.g., Salt Lake City to Folsom, California) and short routes (e.g., San Francisco to Los Angeles), and even Pony Express routes from Fort Bridger, Wyoming, to Bannock City, Montana, and from Fort Abercrombie, North Dakota, to Helena, Montana, along the Northern Overland. There was even a proposal to establish a line of steamboats along the Colorado River from Utah to California (*14, 33*). The proposal was abandoned, however, when the river proved unnavigable. None of the options were as fast as the original Pony Express; for example, the Salt Lake City to Folsom route took 16 to 20 days.

The demand for mail to California did not grow with the population. For example, the USPO collected $304,932 in receipts in California during fiscal year 1867 (*34*), translating to a volume of about 7.26 million pieces at $0.042 per item. (The $0.042 rate is based on an average weight per item of 0.7 oz or 20 gm. There are no statistics on average mail weights from this period, but a two-page letter weighed about 0.5 oz, while a newspaper weighed about 2 oz.) The 1867 volume was lower than the 1860 demand of 8.1 million. Hence, while California's population was growing at 4% per year, the mail volume was decreasing at a rate of 1.7% per year. The decline can be partially attributed to the transcontinental telegraph. In 1872, the Postmaster General, in his annual report, wrote about the rivalry between the USPO and the telegraph. He noted that postage rates had been lowered from $0.25 to $0.03 to offset the telegraph's faster service. It was observed that 2% of all messages were being sent by telegraph and that the proportion "would be about 10%" had the USPO not lowered the price of a postage stamp (*35*). The decline can also be partially attributed to the slowdown in mail delivery. Without the Pony Express and steamships, the coast-to-coast mail delivery time reverted to well over 30 days, as experienced during the 1850s. The telegraph was vital for the rapid transmittal of critical news and information.

MID-1860s PONY EXPRESS MODEL

It is possible to speculate on how the Pony Express would have fared during the 1860s, because there was an unmet niche between the rapid but expensive delivery of short messages and the cheap but time-consuming delivery of longer messages and packages. Thus, one approach is to model cost, delivery time, and message length versus the utilities of the three delivery options. The average transcontinental delivery times were 38 days by railroad and stagecoach (*14*), 13 days by Pony Express (i.e., the same as in 1860–1861), and seconds by telegraph. Data are not available on message lengths, but the maximum number of words possible for the minimum prices were about 600 each for the USPO and Pony Express (at 300 handwritten words per sheet and two sheets per half-ounce), and 10 for the telegraph. Users who needed to send long messages would have opted against the telegraph because of the high cost. The proportions of mail and message transmission handled by each mode can be, at best, estimated from reports. For example, as noted previously, 2% of all messages were being sent by telegraph in 1872—it is assumed that it was a similar percent during the 1860s. Also, in planning for their continued operations into fiscal year 1862 (apparently unaware that the telegraph might be a formidable competitor), Russell, Majors, and Waddell projected that the Pony Express would be carrying 500 letters per trip (*36*). The projection considered that the lowered $1 per ½-oz rate would attract increased use. On the basis of their estimate, the Pony Express would have been carrying mail at a rate of 104,000 items per year, or between 1.3% and 1.4% of the U.S. mail to and from California.

A discrete choice model can be used to estimate the probability that a consumer will choose one product over another. The logit model is a popular discrete choice model form in which probabilities are functions of the utilities of the choices (*37*). Mail and message delivery utilities would include, for example, price, delivery time, and letter or package size; that is, utilities are the aspects of a product that affect its consumption. A trinomial logit model can be used to examine the three mail delivery choices available in the mid-1860s:

$$P(i)=\frac{e^{V_i}}{\left(e^{V_i}+e^{V_j}+e^{V_k}\right)} \tag{1}$$

where

$P(i)$ = probability that selection i is chosen,
V_i = utility of selection i,
V_j = utility of selection j, and
V_k = utility of selection k.

To simplify the analysis, only a national model was developed; that is, only coast-to-coast (i.e., New York to California) message transmission was considered. The utility functions are as follows:

$$V_{\text{mail}} = a(0.03)+b(38)+c(600) \tag{2}$$

$$V_{\text{tele}} = a(6)+b(0.000011574)+c(10) \tag{3}$$

$$V_{\text{pony}} = a(1)+b(13)+c(600) \tag{4}$$

In the three utility functions, V_{mail}, V_{tele}, and V_{pony} pertain to the USPO, telegraph, and Pony Express, respectively. The coefficients of a are the minimum prices, in U.S. dollars, of sending a message by USPO, telegraph, and Pony Express, respectively. The coefficients of b are the travel times, in days, between California and New York. The telegraph's time is assumed to be just 1 s, not considering the additional time it might take for the receiver to actually get a message. Finally, the coefficients of c are the maximum numbers of words that could be sent for the minimum price. The model considers only maximum, rather than average message lengths. There are numerous combinations of (a,b,c) values that work. One combination produces the following utility functions, with price (p_i) as a variable:

$$V_{\text{mail}} = -p_{\text{mail}} - 2.26 \tag{5}$$

$$V_{\text{tele}} = -p_{\text{tele}} - 0.1199985 \tag{6}$$

$$V_{\text{pony}} = -p_{\text{pony}} - 5.51 \tag{7}$$

Market shares of 96.5% for the USPO, 2.1% for the telegraph, and 1.4% for the Pony Express are associated with this set of utility functions. Interestingly, the 1.4% Pony Express share, based on the volume projected by Russell, Majors, and Waddell for fiscal year 1862, would not have been enough to cover expenses. Thus, even their projection was a shortfall. To double the Pony Express market share to 2.8%, the model indicates that the rate needed to be lowered—somewhat substantially—to \$0.30 per ½ oz (\$0.01 per gm). The increased use of the Pony Express would not have offset the decreased receipts, however. Similarly, increasing the rate to \$2 or \$3 would have resulted in losses of two-thirds and five-sixths of the \$1 users, respectively. In all cases, most of the Pony Express users would have switched to regular mail, while telegraph use would have remained stable at 2%. It is clear, therefore, that the Pony Express would have struggled to endure after 1861.

CONCLUSION

The Pony Express ceased to operate in October 1861 amid huge financial losses and a new competitor in the telegraph. Had the Pony Express been financially healthy as of October 1861, however, competition from the telegraph would still have been too great. Although the telegraph captured only 2% of the message transmission market, the proportion of Pony Express users, at \$1 per ½ oz (\$0.035 per gm), would have been even smaller. Lowering the rate to \$0.30 per ½ oz (\$0.01 per gm) might have doubled the number of users to nearly 3% of the market, but the receipts would have been too low to offset the operating expenses. The main issue is that the speed of the Pony Express was greatly exceeded by that of the telegraph. Although the price of the telegraph was much greater than that of the Pony Express, users desiring a cheaper option would have been inclined to use standard mail, thereby leaving the Pony Express with a small market. Hence, even with shrewd pricing strategies, the life of the Pony Express was limited to a short period of time between stagecoaches, the population boom in California, and faster modes of message transmission. The proprietors probably needed to redefine their market and focus on the rapid delivery of packages, reports, and documents, rather than on messages that could be telegraphed. Alternatively, the proprietors would have needed to corner the non-telegraph market, perhaps becoming the exclusive owner of mail delivery to the far western United States. There is a modern-day analogy: the express package delivery industry survives because it serves a specific market. There is no need to challenge a message transmission market that is served very well by e-mail and texting.

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E-Logistics Systems Applications for Service Users and Providers

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This paper reports the findings of a second-round Delphi study (interactive forecasting method) that explored the issues surrounding integrated e-logistics systems, applications, and policy for varying stakeholders. A three-stage qualitative research approach began with a literature survey, which was followed by a first-round online Delphi survey in the second stage. The first-round Delphi generated some ideas and statements that were used in the second-round Delphi survey (third and final stage). In this survey, the participants were given three choices: agree, disagree, and no comment. The achievement of majority agreement or disagreement on these statements was a central point. For this research, the majority agreement–disagreement was sought at three levels: simple majority, significant majority, and vast majority. The research verifies the applicability of a definition of e-logistics established in the first-round Delphi. The study also identifies the fields of cost-effective e-logistics applications for logistics companies. The research suggests ways to develop an integrated e-logistics system and associated European Union policies.

E-logistics is a new terminology defining information and communication technology (ICT) in the processes of transport, logistics, demand, and supply chains. The term has been widely used in different European Union (EU) policy documents and its Seventh Framework Programme research calls. A literature review raised the question of whether the terminology has a widely accepted definition and also raised a question about the use of the term. The following are examples of different forms of the term encountered in a search: e-logistics (*1*), e-logistics (*2*), e-logistics (*3*), E-Logistics (*4*), and E-logistics (*5*). The term may recently have been replaced in policy terms by "e-freight" (*6*).

Core logistics and supply chain management textbooks (*7–9*) do not refer to e-logistics. Rushton et al. (*9*) talk about e-commerce, e-fulfillment, e-procurement, and e-tailing; Mangan et al. (*8*) talk about e-procurement; and Langley et al. (*7*) talk about e-commerce. The definitions, largely from online sources, compare e-commerce to e-logistics, and vice versa, as they explain e-logistics as a peripheral economic transaction that is realized electronically. The current research does not equate e-commerce with e-logistics, even though they have various overlapping systems and functionality. The review and the preliminary expert analysis from the KOMODA project (*2*) show that the data flows in the basic and supporting logistics processes among the supply chain partners (including inside a company) use e-logistics. In the first-round Delphi study, e-logistics (*2*) is defined as "a set of activities based on using the ICT systems and tools, as well as the internet, as the main communication medium in order to maintain logistics process," and this is further verified in the second round.

The literature review shows that e-logistics includes data flows and processes, including ordering, inventory management, transporting, copacking, comanufacturing, vendor-managed inventory, supplier-managed inventory, planning, distribution, etc. While large companies can either develop such bespoke applications or platforms or can invest in off-the-shelf solutions, many micro, small, and medium enterprises (SMEs) may not have the resources and abilities to implement and maintain such systems (*2*). Islam et al. (*10*) noted that that there was a research gap to identify the e-logistics-related issues for varying stakeholders. The current research attempts to addresses this gap with an online survey among the participants of the online survey in the first-round Delphi.

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OBJECTIVES

To address the research gap, this paper has the following objectives: (*a*) verify the acceptability of the definition of e-logistics; (*b*) obtain a comprehensive picture of the fields of e-logistics applications; (*c*) identify the objectives, functionalities, actors, and impact of an integrated e-logistics system; and (*d*) suggest a road map for developing e-logistics systems for varying stakeholders.

PAPER ORGANIZATION

The paper is organized into four parts: the research method (including research approach, respondents profile, survey tool, and sample) is presented, followed by major findings of the research, where the applicability of the definition of e-logistics is verified and the opinion of the Delphi panel on e-logistics applications is offered. This section also sets out the objective of an integrated e-logistics system and verification of the functionalities, actors, and impacts of an integrated e-logistics system. The key findings are summarized and a recommendation is drawn.

RESEARCH METHODOLOGY

Research Approach

In accordance with the objectives of this qualitative research, a Delphi technique was applied. Wellington (*11*) defines Delphi as "a systematic method of collecting opinions from a group of experts, through

a series of questionnaires, in which feedback of the group's opinion distribution is provided between question rounds while preserving the anonymity of the responses." In this method an individual panel member cannot dominate others. The main strengths of the Delphi study are the inexpensive use of experts in the field; the generation of opinions and consensus among a group of experts while preserving their anonymity; and giving panelists the opportunity to revise earlier answers in light of the general opinions expressed by the panel as a whole (*12*). Achieving a consensus is an important criterion in a Delphi study, although Saldanha and Gray (*13*) contend that the result of the Delphi study does not necessarily need the achievement of a consensus. Stuter (*14*) offers the following opinion: "The Delphi Technique and consensus building are both founded in the same principle—the Hegelian dialectic of thesis, antithesis, and synthesis, with synthesis becoming the new thesis. The goal is a continual evolution to 'oneness of mind' (consensus means solidarity of belief), collective mind, the holistic society, the holistic earth, etc." To determine whether a consensus has been achieved, any arbitrary figure could be used, although some justification for it should be made. A number of studies (*15–19*) have accepted consensus as "the majority of responses." For this research, three levels of majority agreement–disagreement are considered: simple majority, significant majority, and vast majority. Simple majority defines a consensus range of more than 50% and up to 70%; significant majority defines a consensus range of more than 70% but less than 85%; and vast majority defines a consensus range equal to or higher than 85%.

This research was conducted in two stages. The first stage consisted of a literature survey (using limited online sources and books) supported by informal interviews with academics, experts, and practitioners. The first stage resulted in the development of a questionnaire for the first-round Delphi; in the second stage, two rounds of Delphi online surveys were conducted.

Respondent's Profile

The questionnaire included investigation of the stakeholder's profile in terms of geographical coverage (central-, northern-, southern-, western- and non-European) of company operation:

- SME versus non-SME;
- Different transport modes: road, rail, maritime, intermodal, inland waterways (IWW), and air;
- Expertise in ICT (basic understanding, competent user, expert, and none);
- Expertise in the area of freight transport and logistics; and
- Company involvement in the provision or regulation of freight transport and logistics (logistics and transport service provider, terminal operators, academic and researcher, shippers, and authorities).

This respondent profile was also used in the third (summary) stage, where an online survey was conducted among the participants of the survey's second stage. The first-round Delphi questionnaire was designed to gather opinion on different e-logistics issues and ideas that are used in the questionnaire for the second-round Delphi (third stage).

Research Questions

In the first-round Delphi study, the definition of e-logistics was agreed upon as "a set of activities based on using the ICT systems and tools, as well as the Internet, as the main communication medium in order to maintain logistics process." Also, some e-logistics applications were identified and some research questions and issues were gathered from the Delphi panel. Building on the findings of the first-round Delphi, this paper examines six categories of main research questions.

The first category research question explored the applicability of the definition of e-logistics as "a set of activities based on using the ICT systems and tools, as well as the Internet, as the main communication medium in order to maintain logistics process."

The second category research question looked at the fields of usage of 19 cost-effective e-logistics applications: Terminal operational optimization system, port community systems, transport statistics and assessment systems, multimodal route planning, customs and other regulatory authorities, vehicle tracking and tracking systems, cargo monitoring systems, and a "significant majority" agreement consensus on the remaining 12 e-logistics applications [supply chain execution systems, ecommerce applications, electronic data interchange (EDI), fleet management systems, cargo tracking and tracing systems, route guidance systems, warehouse management systems, invoicing systems, supply chain planning systems, booking, decision support systems, and organizational management systems]. An integrated logistics system requires that there be no gaps in the planning process and hence no areas where planning can go astray by failing to cover all activities. The research focuses on the integrated e-logistics system. The statements in Categories 3 to 6 are designed to define an integrated e-logistics system.

The third category research questions explored the objective and targets of an integrated e-logistics system. Opinions were solicited for the following statements: An integrated e-logistics system

- Should be an initiator for interconnected national e-logistics platforms for pan-European coverage,
- Should be targeted only to SMEs,
- Should focus on the provision of standards (in processing, technology, message formats, and administrative document formats) for the development of ICT for logistics in Europe instead of providing real logistics solutions, and
- Should focus on the provision of certain existing standards and future national e-logistics systems.

The fourth category research questions explored the services and functionalities of an integrated e-logistics system. Opinions on the following statements were solicited: An integrated e-logistics system

- Should be an open online platform,
- Does not need interfaces with the proprietary applications,
- Should be able to substitute for proprietary e-logistics applications,
- Should use an international open application standard,
- Should publish available logistics services across Europe,
- Should comply with European transport regulations, and
- Should encompass financial incentives for the users (tax incentives, administrative facilitations, toll free passages).

The fifth category's research questions explored the actors of an integrated e-logistics system. Opinions were solicited for the following statements: An integrated e-logistics system

- Should emerge from a public–private partnership,
- Should be operated and managed by a neutral organization,

- Should become mandatory for all supply chain partners,
- Does not need standardized transaction formats,
- Should encompass operational incentives for the users (priority services to terminals, access to transport information, etc.), and
- Should be built in stages starting with, for example, port–terminal community.

The sixth category's research questions examined the foreseeable impacts of an integrated e-logistics system. Opinions were solicited for the following statements: An integrated e-logistics system

- Will distort competition in the field of logistics ICT,
- Will create additional costs in the management of transport chains,
- Will not be accepted by large companies,
- Will expose sensitive commercial data online,
- Will reduce investment costs for logistics ICT platforms, and
- Will increase the power of larger companies over SMEs.

Survey Tool

With the increasing use of the Internet, computerized online surveys are viable in the developed countries that were the focus of this research. Because the online survey tool requires facilities and infrastructures such as an Internet connection and a computer, the tool may be less suited to many developing countries. Compared with face-to-face or telephone interviews, an online survey has the advantage that a respondent can complete and return the questionnaire according to a personally suitable or available time frame. As with the mail survey, it offers anonymity. Moreover, compared with a postal survey, this tool has a delivery advantage if the e-mail address is correct and active. However, a possible disadvantage is that upon seeing the e-mail's subject-line coupled with an unknown sender's name, many respondents may delete the e-mail questionnaire without opening it. Thus, some experts suggest careful use of this tool (*19*). The ability to capture the data electronically and analyze immediately without processing is highly advantageous to the researcher.

There are a number of online survey tools, including Survey Monkey and Bristol Online Surveys (BOS). SurveyMonkey (*20*) is marketed as

> intelligent survey software for primates of all species. It has a single purpose: to enable anyone to create professional online surveys quickly and easily. Using just a web browser, researchers can create a survey tool with their intuitive survey editor using a web browser. They can select from over a dozen types of questions (multiple choice, rating scales, drop-down menus, and more). There are powerful options that allow researchers to require answers to any question, control the flow with custom skip logic, and even randomize answer choices to eliminate bias. SurveyMonkey is flexible and scalable enough to meet the needs of a wide range of people: whether you're managing HR for a multinational organization or you're simply trying to gather feedback for your blog.

BOS (*21*) is marketed as

> an easy-to-use service tool that allows researchers to develop, deploy, and analyze surveys via the Web. No complicated setup or technical knowledge is required. The online reports allow real-time analysis of survey results. Researchers can cross-tabulate results, filter by question response; compare results between surveys, step through responses, and download data for use in other packages. Newcastle University holds a BOS license and allows researchers and other users to conduct as many surveys as they want. Moreover, the BOS service also offers free e-mail and telephone support in addition to an extensive online knowledgebase.

Because SurveyMonkey was developed commercially, a fee would have been charged for its use in this survey. In contrast, the BOS online tool was developed by the University of Bristol, a leading research institute in the United Kingdom. BOS was chosen for this survey because the functionality was satisfactory, it required no additional fees, and the use of an academic service was expected to generate trust and engender a higher response rate.

Sample

In December 2008, the first-round Delphi requested the e-mail participation of 1,000 potential respondents (mainly from EU-27 countries, with a small minority from outside) from August 15 to 30. This pool was drawn from academics, experts, and practitioners in the logistics, ICT sectors, academia, and consultancy. A total of 99 responses were received, but 17 of them were invalid because of duplications and missing essential information. The total number of valid responses was 82 (response rate about 8.2%), of which 10 were from outside EU-27 countries (Australia, Mexico, Norway, Serbia, and Turkey). The majority of the respondents belonged to SMEs; however, 38.64% of all SMEs were academics, consultants, and government employees, and 32.53% of the whole response came from academics and consultants. About half of them were competent with ICT, and about 83% of them stated they had either an expert or competent level of experience in the logistics area. As a Delphi norm, the second-round questionnaire was sent to only the 82 respondents who took part in the first round. Of these, only 40 valid Delphi panel responses from the second round are shown in Table 1. This is a qualitative Delphi study that does not require a statistically significant sample size. Although a bigger sample might result in a more meaningful and reliable study, the methodology is dependent on expertise rather than numbers. There are many published Delphi studies with lower sample sizes than this research. Examples of very recent studies include Shaikh (*22*), with 30 Delphi panel size; Al-Mabrouk and Soar (*23*), with 30 Delphi panel size; Boone et al. (*24*), with 20 Delphi panel size; and Brewer and Gajendran (*25*), with 15 Delphi panel size.

MAJOR FINDINGS

Definition of E-Logistics

The applicability of the definition "a set of activities based on using the ICT systems and tools, as well as the Internet, as the main communication medium in order to maintain logistics process" was explored. Figure 1 displays the varying opinion on the definition. The Western EU panel had simple majority agreement, but the panels from terminal operator, ICT expert, IWW, non-EU, and southern EU group had 100% agreement.

Cost-Effective Use of E-Logistics Applications

The Delphi panel agreed that 17 of 19 e-logistics applications are cost-effective for logistics companies (see Figure 2). Only two appli-

TABLE 1 Delphi Panels in the Second Survey

Delphi Panel Type	Delphi Panel Size	Total Number
Total	40	Total
Western EU	11	40
Southern EU	3	Geographical profile
Northern EU	8	
Central EU	16	
Non-Euro	2	
SME	23	40
Non-SME	17	SME versus non-SME
Road	17	65
Rail	8	Transport mode
Maritime	6	Note: In the analysis by a transport mode, the total number of replies is 65 (instead of 40). This is because the respondents may have opted for several modes of transport.
Intermodal	22	
IWW	4	
Air	6	
ICT: expert	11	40
ICT: competent	17	Level of ICT expertise
ICT: basic	12	
Logistics: expert	16	40
Logistics: competent	14	Level of expertise in freight and logistics
Logistics: basic	9	
TO	4	40
LSP	13	Provision or regulation of freight logistics services
Researcher	20	
Authority and policy maker	2	
Shipper	1	

cations achieved no majority consensus. None of the applications achieved vast majority consensus, but 10 achieved significant majority, and seven achieved simple majority consensus.

Definition of Integrated E-Logistics System

The research was carried out in context of the EU Freight Logistic Action Plan (*26*), which states the following: "To promote innovation, the Action Plan will encourage the use of information and communication technologies in freight. It outlines the vision of paperless information flows accompanying the physical shipment of goods. . . . The paperless transfer of information on the transport of goods will also help the simplification of freight flows." Various research activities have been created and followed from the action plan. For example, the Freightwise Project (*27*) developed the concept of "integration through simplicity," using standardized messaging rather than bilateral and bespoke solutions. Freightwise built on the ARKTRANS (*28*), the Norwegian system framework architecture for multimodal transport systems, supporting freight and passenger transport. The SINTEF (*29*) report was initiated to establish a Freightwise Framework (FWF) for efficient co-modal freight transport. The aim is to simplify the interaction between stakeholders by defining the main roles that need to interact in order for such activities to be optimally efficient. The purpose of the reference model is to divide the freight transport domain into sub-domains and define necessary interactions between them. The main roles are transport user and transport service provider, supported by the transportation network manager and the transport regulator. Freightwise has defined a generic specification of a transport service (a transport service description) and a small set of information objects that need to be exchanged between the four main roles (*30*). The core of the FWF is being incorporated into the Universal Business Language 2.1, developed by OASIS (*31*), has been released under a Creative Commons license, and has been adopted by various EU initiatives.

The EU has established liaison with the U.S. Department of Transport (DOT) on the Freightwise and eFreight projects to explore the harmonization of the FWF with the U.S. Electronic Freight Management (EFM). EFM is a U.S. DOT–sponsored project that applies Web technologies to improve data and message transmissions among and between supply chain partners. It promotes and evaluates innovative e-business concepts, enabling process coordination and information sharing for supply chain freight partners through public–private collaboration (*32*). Under this EFM initiative, the Kansas City Electronic Freight Management project defined, built, deployed, and evaluated an EFM platform for DEMDACO, a suburban Kansas City–based importer of household gift and decorative items (*33*).

However, there are other strands of thought on this in the European political community; therefore, the project also explored concepts that were raised in interviews: national platforms where a state provided a single platform to run all applications as a neutral party, or the view that integration would be achieved through the dominance of key actors enforcing compliance on their partners. To that end, and given the limited range of questions and the open-ended nature of Delphi, the research explored the nature of integrated e-logistics platforms in the political context of EU policy.

Objectives of Integrated E-Logistics System

There were four statements to explore the objectives of an integrated e-logistics system. All statements achieved majority consensus, by agreement or disagreement (see Figure 3). The following two statements had a simple majority agreement consensus:

- An integrated e-logistics system should focus on the provision of standards (in processing, technology, message formats, and administrative documents formats) for the development of ICT for logistics in Europe instead of providing real logistics solutions (Statement A in Figure 3) and
- An integrated e-logistics system should focus on the provision of certain existing standards and future national e-logistics systems (Statement B in Figure 3).

Figure 3 shows some differences among the panel groups. For example, the western EU panel had a simple majority agreement with the following statement: "An integrated e-logistics system should focus on the provision of certain existing standards and future national e-logistics systems," but the northern EU panel had no majority agreement consensus. There is also a difference in the level of competence in ICT and the expertise in the freight transport sector.

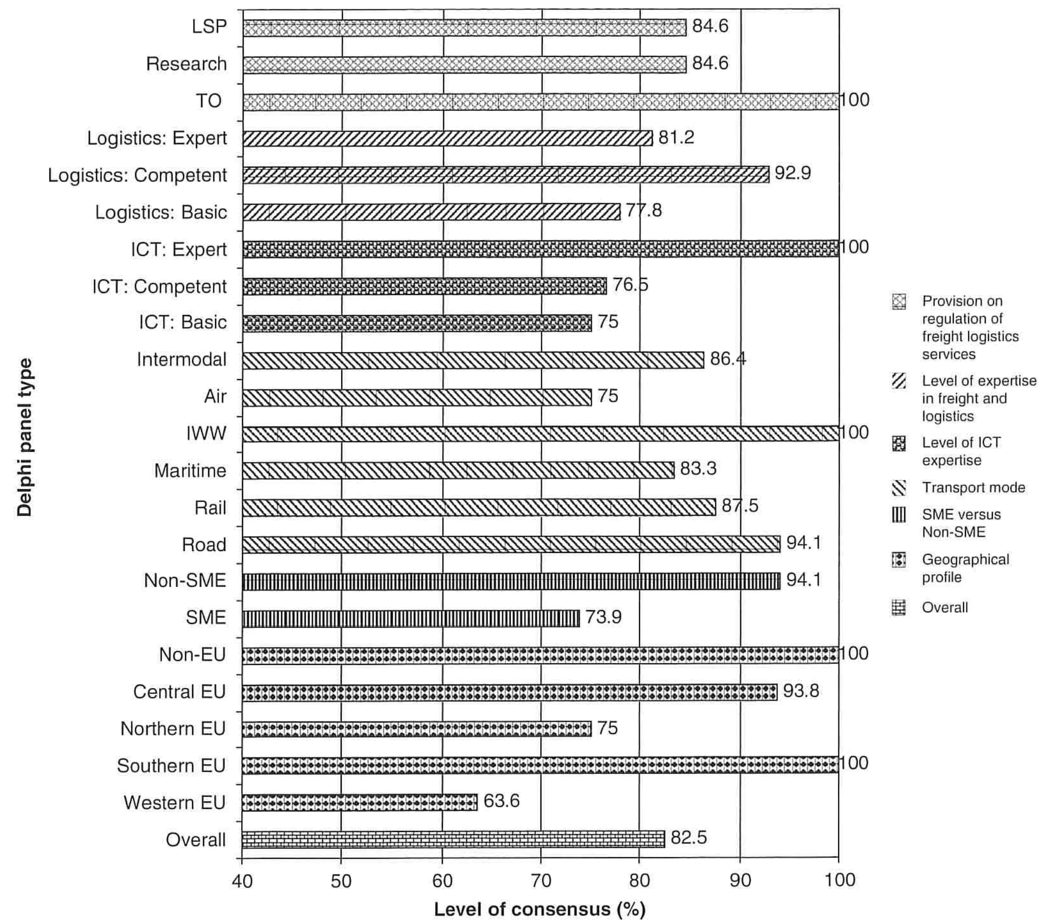

FIGURE 1 Delphi panel on applicability of definition of e-logistics.

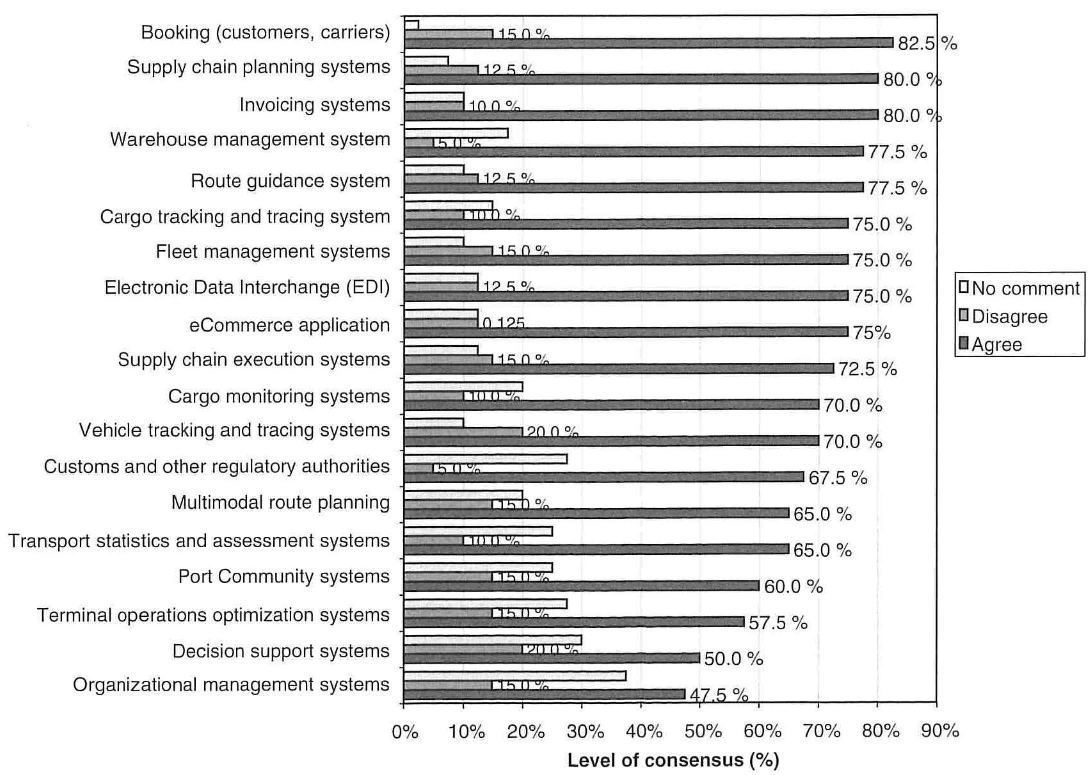

FIGURE 2 Delphi panel on cost-effective e-logistics applications.

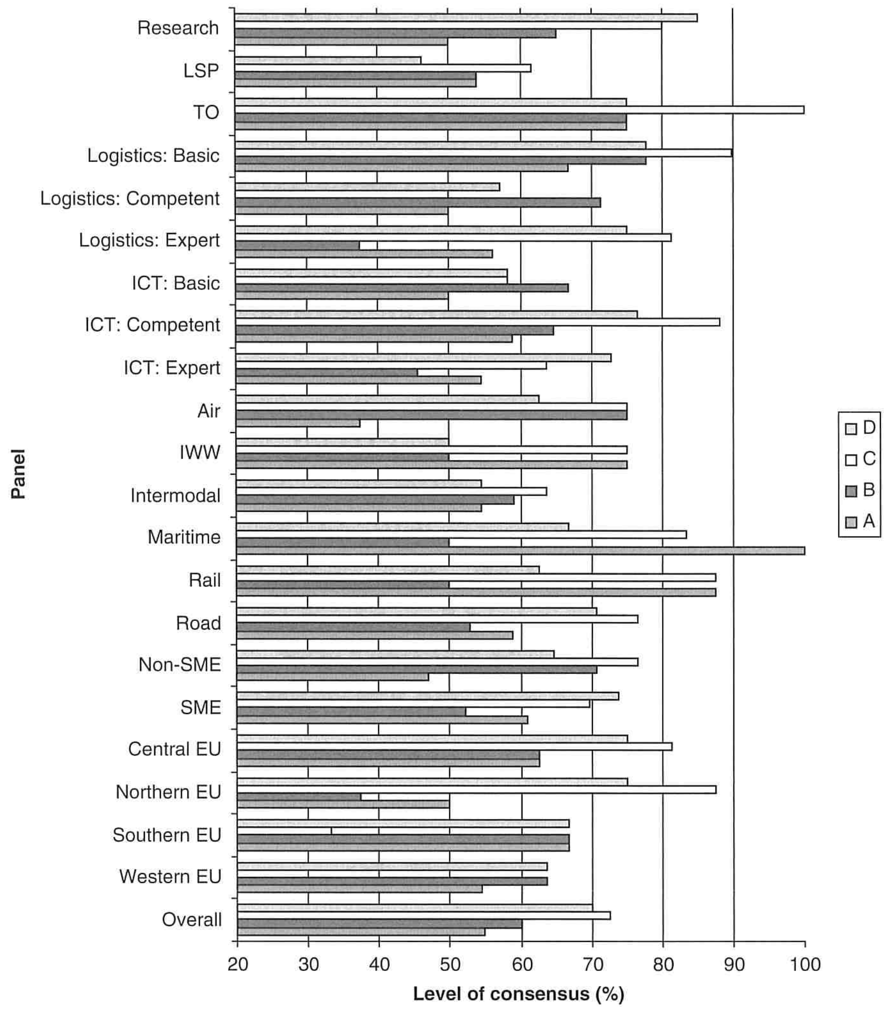

FIGURE 3 Delphi panel on objective of integrated e-logistics system.

But the statement "an integrated e-logistics system should only be targeted to SMEs" (Statement C in Figure 3) had a simple majority disagreement consensus, and the statement "an integrated e-logistics system should be an initiator for interconnected national e-logistics platforms for pan European coverage" (Statement D) had a significant majority agreement consensus.

Functionalities of Integrated E-Logistics System

There were seven statements to explore the "services and functionalities" for an integrated e-logistics system (see Figures 4 and 5). All statements have achieved majority agreement consensus, with the following four statements (see Figure 4) having a vast majority agreement consensus:

- An integrated e-logistics system should be an open online platform (Statement A),
- An integrated e-logistics system should use an international open application standard (Statement B),
- An integrated e-logistics system should publish available logistics services across Europe (Statement C), and
- An integrated e-logistics system should comply with European transport regulations (Statement D).

Figure 4 shows that there are few differences among the panel groups on the above four statements. Rather, they had consistent "vast majority" agreement on these statements.

But the remaining three statements (see Figure 5) had a "simple majority" agreement consensus:

- An integrated e-logistics system should encompass financial incentives for the users (tax incentives, administrative facilitations, toll-free passages) (Statement A in Figure 5),
- An integrated e-logistics system should be able to substitute for proprietary e-logistics applications (Statement B in Figure 5), and
- An integrated e-logistics system does not need interfaces with the proprietary applications (Statement C in Figure 5).

Figure 5 shows that there are some differences among the panel groups on the three statements. For example, the western EU panel had "simple majority" agreement with the statement "An integrated e-logistics system does not need interfaces with the proprietary applications," the central EU panel was divided, and the northern EU panel had no majority agreement. On this statement, there is a

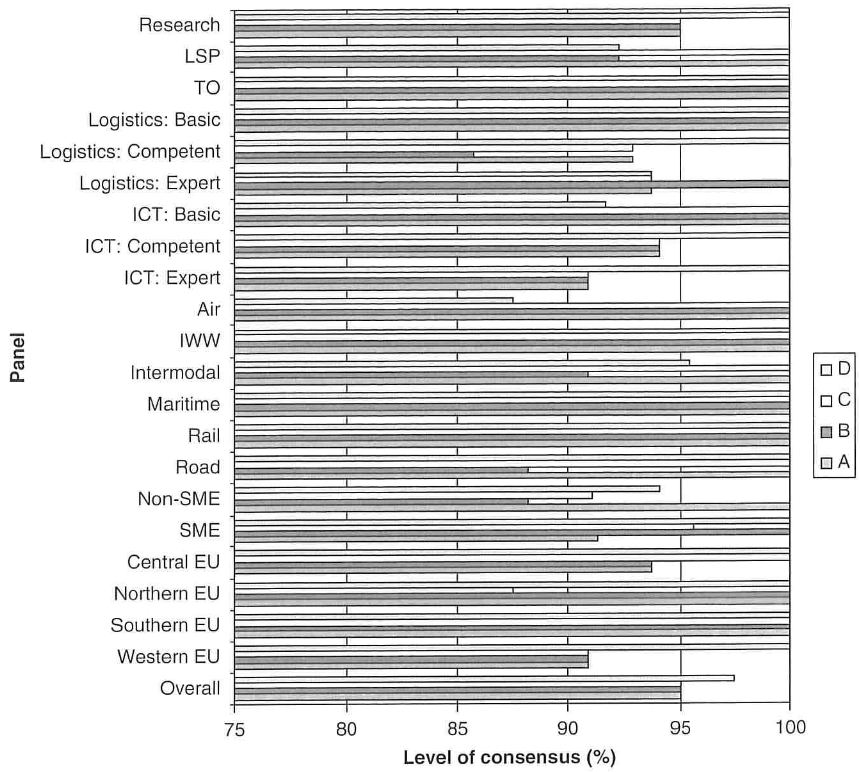

FIGURE 4 Delphi panel on functionalities of integrated e-logistics system.

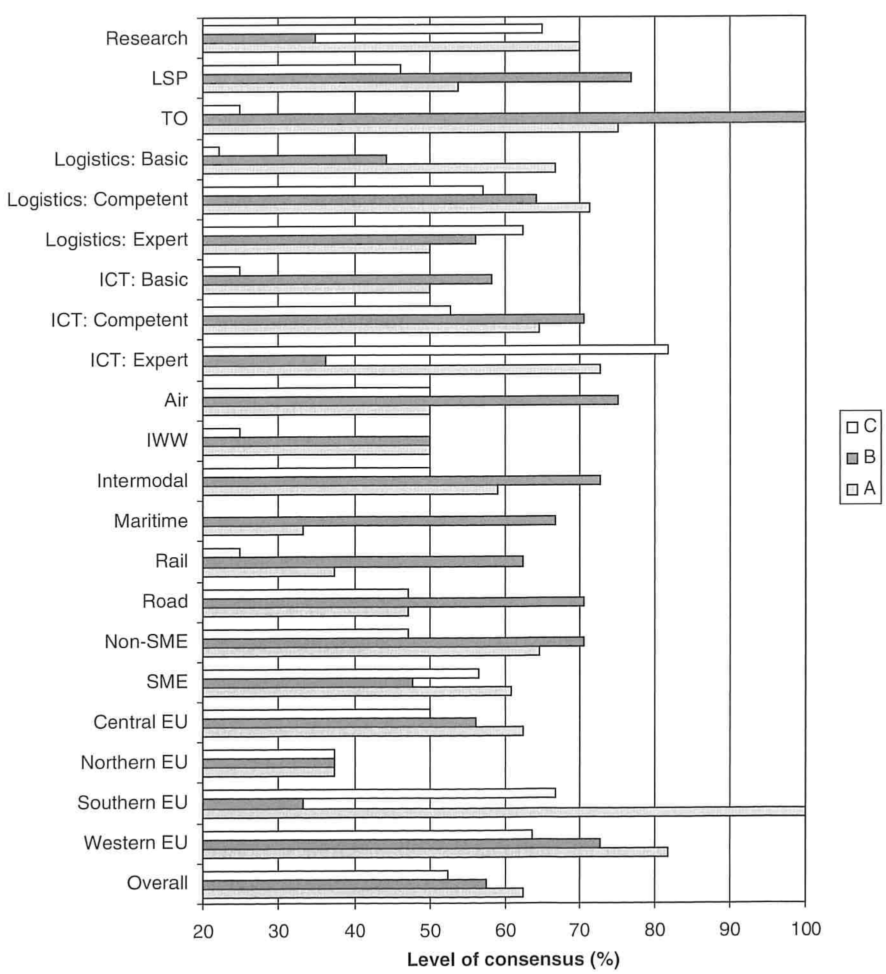

FIGURE 5 Delphi panel on functionalities of integrated e-logistics system.

difference of opinion in all panel groups. For example, the SMEs had simple majority agreement, while the non-SMEs had no consensus.

Actors for Integrated E-Logistics System

There were six statements to explore the "actors" for an integrated e-logistics system, of which the following two statements had no consensus:

- An integrated e-logistics system should emerge from a public–private partnership and
- An integrated e-logistics system should become mandatory for all supply chain partners.

Figure 6 shows that these statements have achieved different levels of agreement–disagreement consensus opinions. The following two statements had a simple majority agreement:

- An integrated e-logistics system should be operated and managed by a neutral organization (Statement A in Figure 6) and
- An integrated e-logistics system should encompass operational incentives for the users (priority services to terminals, access to transport information, etc.) (Statement B in Figure 6).

There are some differences among the panel groups on these two statements. For example, on the statement "An integrated e-logistics system should be operated and managed by a neutral organization" the southern EU panel had 100% majority agreement, while the northern EU panel had no majority agreement, and the remaining EU panels had simple majority agreement.

On the statement "an integrated e-logistics system does not need standardized transaction formats" (Statement C in Figure 6), the panel had a significant majority disagreement consensus. On this statement there are differences of opinion as well. For example, the central EU panel had simple majority disagreement, while the remaining panels had vast majority disagreement. On the statement "an integrated e-logistics system should be built in stages starting with, for example, port–terminal community" Statement D in Figure 6), the panel had a significant majority agreement. On this statement, there are differences of opinion as well. For example, the southern EU panel had 100% majority agreement, but the western EU panel had simple majority agreement, while the remaining EU panels had significant majority agreement.

Impact of Integrated E-Logistics System

There were six statements to explore the "foreseeable impact of an integrated e-logistics system," of which the following three statements had no consensus:

- An integrated e-logistics system will distort competition in the field of logistics ICT,

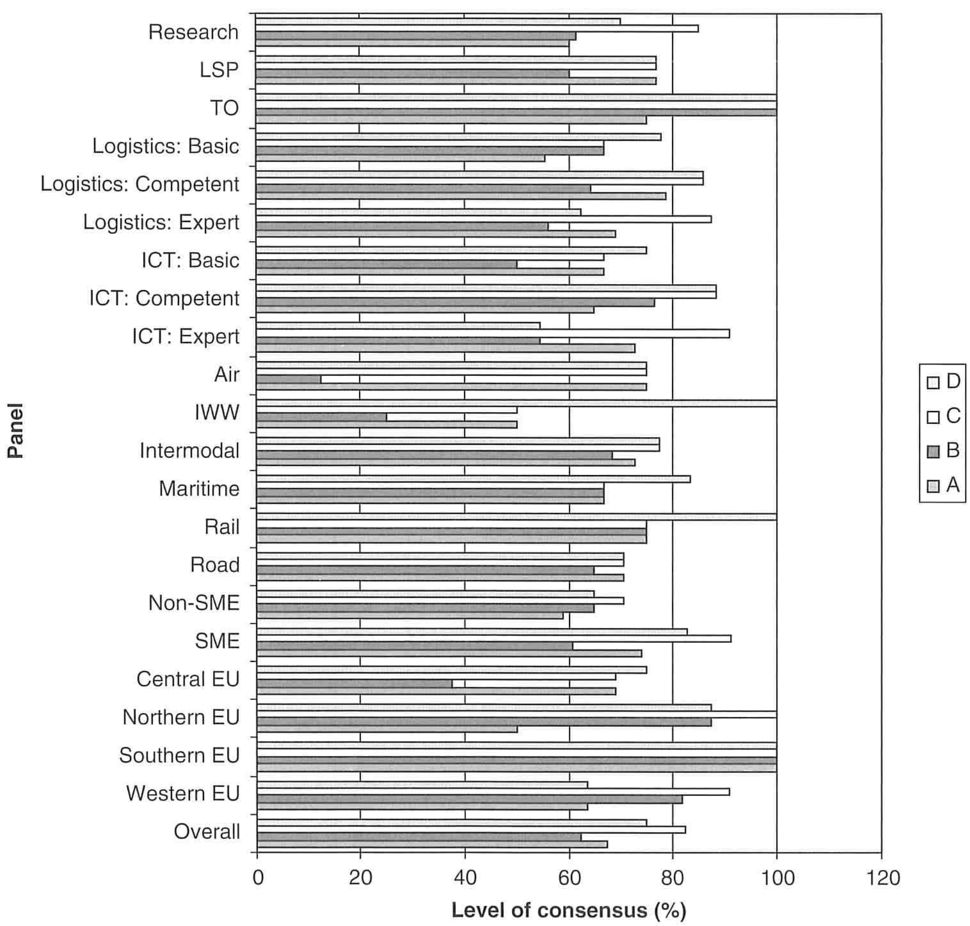

FIGURE 6 Delphi panel on actors of integrated e-logistics system.

- An integrated e-logistics system will not be accepted by large companies, and
- An integrated e-logistics system will expose sensitive commercial data online.

On the other hand (see Figure 7), the panel had a simple majority agreement consensus on the statement "an integrated e-logistics system will reduce investment costs for logistics ICT platforms" (Statement A in Figure 7). There is a difference of opinion on this statement among panel groups. For example, the western EU panel had no consensus agreement, the northern EU panel was divided, and the remaining EU panels had simple majority agreement. The following two statements had a simple majority disagreement consensus:

- An integrated e-logistics system will create additional costs in the management of transport chains (Statement B in Figure 7) and
- An integrated e-logistics system will increase the power of larger companies over SMEs (Statement C in Figure 7).

There are differences of opinion on these two statements among different panel groups. For example on the statement "An integrated e-logistics system will create additional costs in the management of transport chains," the western EU panel had a significant majority disagreement, while the remaining EU panel groups had a simple majority disagreement.

SUMMARY

E-Logistics is a new terminology in the field of logistics. The current research attempts to define the terminology within its fields of e-logistics applications and to identify and verify some key issues and notions that are linked to an integrated e-logistics system. To accomplish this, a qualitative research technique—Delphi study—was applied. The current research reports the key findings of the second-round (final) Delphi. The second-round online Delphi survey was conducted from March to May 2009. The questionnaire was sent only to the Delphi panel (*82*) that took part in the first round that was conducted from August 15 to December 30, 2008. The following sections summarize the key findings of the study. The following findings can help develop and maintain a cost-effective and integrated e-logistics system.

Definition of E-Logistics System

The study found that the definition of e-logistics as "a set of activities based on using the ICT systems and tools, as well as the internet, as

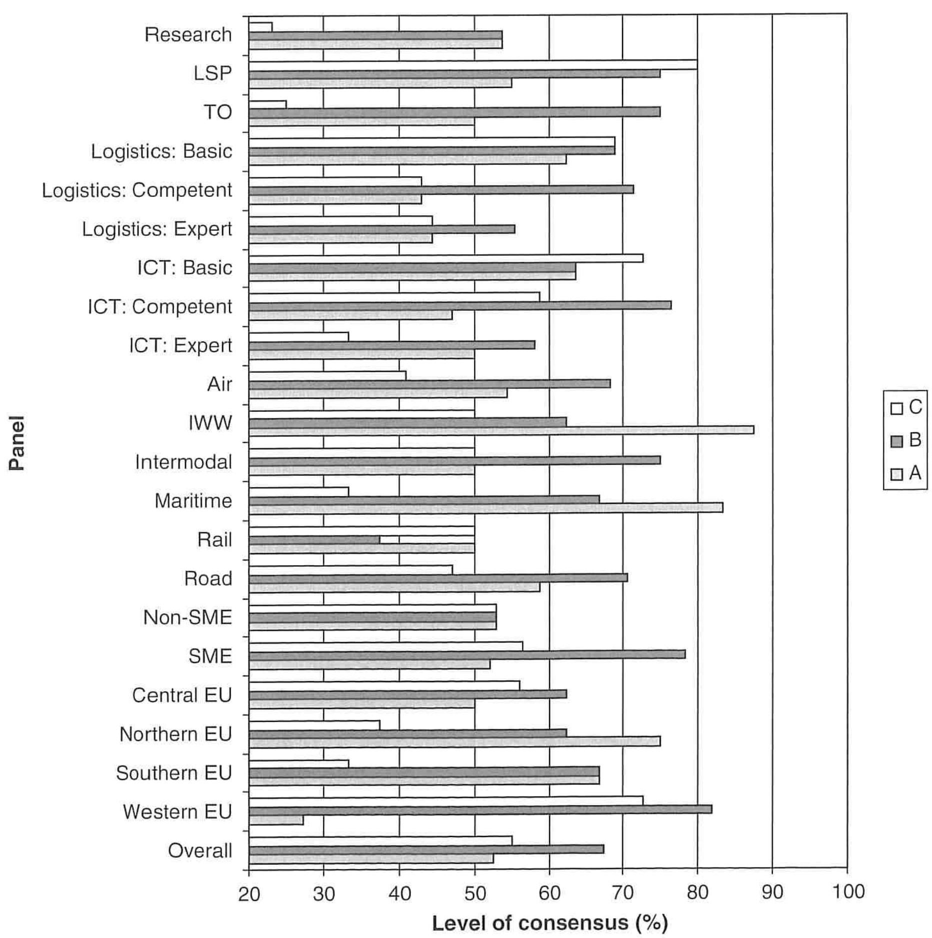

FIGURE 7 Delphi panel on impact of integrated e-logistics system.

the main communication medium in order to maintain logistics process" is widely applicable in the freight logistics sectors.

E-Logistics Applications

According to the significant majority Delphi panel, the e-logistics applications can be cost-effective for a logistics company in the following areas: booking, supply chain planning systems, invoicing systems, warehouse management systems, route guidance systems, cargo tracking and tracing systems, transport resource applications, fleet management systems, EDI, e-commerce applications, and supply chain execution systems.

The Delphi panel had simple majority consensus on the following e-logistics applications: terminal operational optimization system, port community systems, transport statistics and assessment systems, multimodal route planning, customs and other regulatory authorities, vehicle tracking and tracking systems, cargo monitoring systems, and supply chain execution systems.

There were two fields of e-logistics applications that achieved no majority consensus by the panel: decision support system and organizational management system.

Objectives of Integrated E-Logistics System

The integrated e-logistics system (and especially the body managing the system and the platform) should be an initiator for interconnected national e-logistics platforms for pan-European coverage. The e-logistics system should not be targeted only to SMEs. The system should focus on the provision of alternative but not exclusive standards (in processing, technology, message formats, and administrative documents formats) for the development of ICT for logistics in Europe instead of providing real logistics solutions. The system also should focus on and support future national e-logistics systems.

Functionalities of Integrated E-Logistics System

The e-logistics system should include and be supported by an open online (co-modal) platform. The system should use international open standards and should be able to publish or provide information about available logistics services across Europe. The e-logistics system needs to comply with European transport regulations and should also encompass financial incentives (such as tax incentives, administrative facilitations, and toll-free passages) for the users. On service provision and portal level, the system should be able to offer an alternative for proprietary e-logistics solutions and applications. However, the system cannot be isolated from the world around it and thus needs interfaces with the proprietary applications.

Actors for Integrated E-Logistics System

An integrated e-logistics system (including applications, electronic tools and platforms, alternative functionalities, etc.) should be operated and managed by a neutral organization. It should encompass operational incentives (such as priority services to terminals and access to updated transport information) for its users. The e-logistics system needs an open, standardized transaction format. The integrated system should be built in stages, starting with, for example, port–terminal community.

Impact of Integrated E-Logistics System

The integrated e-logistics system will not (or should not) create additional costs in the management of transport chains. Rather, the system will reduce investment costs for logistic ICT platforms. The panelists see that an integrated e-logistics system will not increase the power of larger companies over SMEs.

CONCLUSION

The goal of the authors was to provide a road map for developing an integrated e-logistics system as a platform that can be used by all types (e.g., SME and non-SME) of supply chain partners. From the findings of the current research it is concluded that an integrated e-logistics system will remove gaps among the logistics and supply chain partners using different e-logistics systems and applications, depending on a company's type of business. To accomplish this as a cost-effective operation, companies will use such e-logistics applications as booking, supply chain planning systems, invoicing systems, warehouse management systems, route guidance systems, cargo tracking and tracing systems, fleet management systems, EDI, e-commerce applications, and supply chain execution systems. Of these, some e-logistics applications (such as booking, invoicing, and cargo tracking and tracing systems) will be used by both the logistics service provider and the user, while other applications (such as supply chain planning systems, warehouse management systems, route guidance systems, and fleet management systems) will be used only by service providers.

Because a supply chain partner of one chain can be a partner of another supply chain that may compete directly or indirectly with the first, there is a serious issue: the commercial sensitivity of the data. The platform will be operated and managed by a neutral organization, which will be an initiator for an interconnected national e-logistics platform for pan-European coverage. The platform will use an open online system, with the provision of alternative and international open standards to facilitate all users. While the research supports the idea of neutrality, the owner of such a platform is unclear, as indeed is the question of whether there would be multiple platforms.

The research supports the EU policy objective of seamless, paperless transactions in the EU and also supports the use of open standards such as the Freightwise Framework. However, the research is ambiguous about the degree of functionality that such a platform should offer. On one hand, the panel stated that provision of standards was all that was required (Statements A and B, Figure 3), yet elsewhere the system is expected to publish available logistics services (Statement C, Figure 4) and to make provision for substitution of proprietary applications (Statement B, Figure 5). There are a variety of messaging platforms associated with the Freightwise Framework, with proprietary freight trading platforms and with initiatives such as EFM in the United States. There may be a demand for the outsourcing of broader functionality based on this research.

The impact of an integrated e-logistics system is seen as benign by the panel, avoiding distorted competition, large-company avoidance, exposure of commercial data, extra costs, or the dominance of large companies over smaller. To the extent that one can imagine platforms

that could deliver all of these benefits, one might view the panel's views as aspirational forecasts.

RECOMMENDATIONS FOR FUTURE RESEARCH

This paper has explored part of the subject of ICT and logistics in the EU as well as the likely trends and developments in e-logistics as evidenced by the consensus reached. The authors are confident that the definition of e-logistics is widely applicable in the logistics field and that the e-logistics applications can be cost effective in the applications that achieved significant majority consensus.

In various areas, the research was unclear, ambiguous, or opened further avenues for research. Further research into the detailed functionality of the e-logistics platform is recommended, whether it is a messaging platform between existing systems using standardized messaging or whether functionality will be delivered to replace proprietary or bespoke systems. The ownership and governance of such a platform would be key to addressing the various impacts of such a platform, despite the optimism of this Delphi panel. The degree to which the states should facilitate or provide such platforms in the liberal economy of the EU would need to be addressed, as would the question of whether multiple competing platforms would be a more viable and appropriate solution. This research was EU focused, yet in a global logistics industry, it would be beneficial to develop a comparative study between the key trading regions, say North America, Japan, China, EU, and South America.

The open and qualitative nature of Delphi raises questions, but future research based on more developed definitions of e-logistics platform functionality would be appropriately tested with smaller-scale and more focused quantitative research, although such research may be problematic on a multinational basis.

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The Freight Transportation Planning and Logistics Committee peer-reviewed this paper.

Impact of Transportation Policies on Competitiveness of Brazilian and U.S. Soybeans

From Field to Port

J. Daniel Friend and Renato da Silva Lima

Because of increased international consumption, soybeans have become one of the world's top commodities. Brazil and the United States, the world's two largest soybean exporters, possess unique agricultural commodity infrastructure schemes for production and transportation. The goal of this paper is to examine the differences between transportation systems and infrastructure of the two countries, and look at how these differences affect their respective commodity transportation policies. A theoretical overview of the essential role transportation plays in business logistics is followed by an analysis and comparison of the Brazilian and U.S. transportation systems. Drawing on previous U.S. Department of Agriculture studies of U.S. and Brazilian commodity transportation, landed cost price formation analyses are performed, taking into account production, internal transportation, and freight tariffs. Examples of landed cost price formation are also given to enrich the information provided. It is shown that in certain cases Brazilian internal soybean transportation costs can represent 230% more than those of the United States. On the basis of the literature review, the effect of transportation policies on the total landed cost of soybeans on the world marketplace are examined, as are reasons for why Brazilian soybeans suffer a competitive disadvantage from field to port. The current situation and what could be done to potentially improve Brazilian internal transportation policies is also discussed.

Agricultural commodity trade, and particularly the soybean market, represents an opportunity for Brazil to position itself as a leader in the world market. Among the three most commonly produced grains in the global agricultural market—soybeans, wheat, and corn—soybeans maintain the highest price on the market, almost two and three times more expensive than wheat and corn, respectively (*1*). Considering current investments in research and large-scale production of biofuels, an increase in soybean demand can be foreseen. Brazil is the second largest soybean exporter in the world after the United States and is also one of the most important competitors in the global oilseed market (*2*).

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As the world's two principal soybean producers, Brazil and the United States also export the majority of the world's soybeans and, thus, compete for the edge in the world's largest soybean-consuming markets of China and the European Union. Currently, the world's three principal soybean exporting nations—the United States, Brazil, and Argentina—contribute to nearly 90% of the international trade. These data are represented in Figure 1 (*3*).

The expected dramatic increase in Brazilian soybean production in the coming years has been cited as one of the three major structural changes occurring in the international grain trade, along with Chinese demand levels and U.S. ethanol production (*4*). According to the U.S. Department of Agriculture's (USDA) projections, by the year 2019 Brazilian soybean exports will increase by 40%. This expected substantial change has been credited to the use of large reserves of previously uncultivated land and policies that enable farmers to respond to higher prices. Areas in the interior of Brazil, specifically in the states of Mato Grosso and Mato Grosso do Sul, which had previously underused their land resources, have begun to expand the harvest capacity by simply planting more acreage. The increased South American pressure, specifically from the growth in Brazilian soybeans, will result in the reduction of the U.S. total market share from nearly 40% to 30% by the end of the projections in 2019 (*1*). This shift in the balance of power in the soybean market will create opportunities for profit in Brazil.

However, the Brazilian soybean market currently suffers from a disadvantage in comparison with its world-market competitors: cost of transport. Among competitors, Brazil maintains the lowest farm-level cost of production (*5*) but loses out on this advantage between the field and the port on the way to the international market because of the large distances traveled by inefficient means of transportation in comparison with the competitors (*6*).

In logistical terms, soybeans are a low-aggregated-value product, turning its transport policy into an essential element in cost control and, ultimately, competitiveness. According to Dornier et al. (*7*), transport policy involves the choice between modes of transportation, decisions about delivery size, and routing, and scheduling. A product's transportation policy is highly related to client service, stock, and storage locations.

The cost of transporting soybeans in Brazil is considerably higher than in the United States. In 2007, the Agricultural Marketing Service and the USDA measured the internal transport costs of Brazilian soybeans to be three times more than that of American soybeans (*8*). It is generally accepted that as infrastructural systems improve, the cost of transportation is reduced, thus implicating a reduction of the cost of

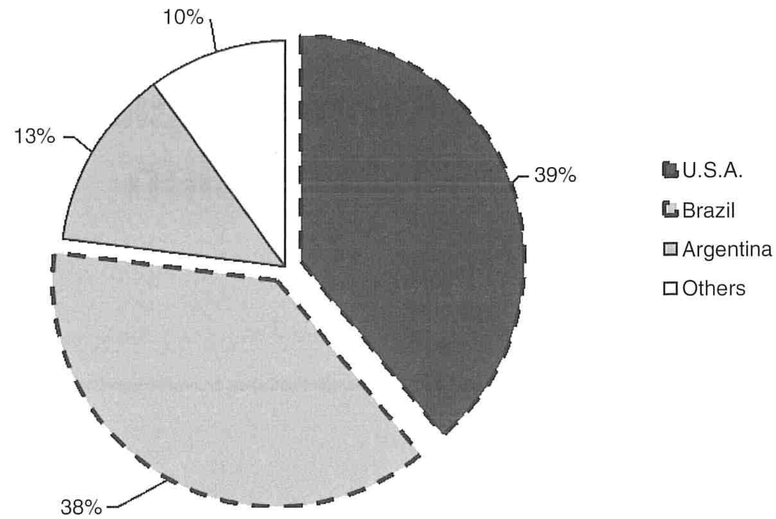

FIGURE 1 Leading soybean exporting nations, 2008. (Source: *Agriculture Statistics Annual 2008*, U.S. Department of Agriculture.)

the product in general (*9*). In other words, more economically efficient means of transportation spell an increased competitive advantage for the product on the market.

This paper evaluates the respective modes of transportation of soybeans from Brazil and the United States. The introduction is followed by a discussion about key theories and definitions dealing with transportation as a component of the logistics that will be called upon throughout the paper. Next, the different modes of transporting soybeans in the countries in question will be analyzed. The paper concludes with a discussion of the data presented and a summary of the details and general discussion of the current situations and implications for future transportation developments in Brazil and the United States.

LOGISTICS AND INTERNATIONAL COMMODITY TRANSPORTATION

Logistics have never performed such an important role in organizations (*7*). According to the definition offered by Dornier et al., "logistics is the flow management between marketing and business functions. The current definition of logistics encompasses larger amplitude than in the past" (*7*).

With respect to international logistics, Ballou goes on to state that "inexpensive transportation has allowed domestic companies to . . . secure raw materials that are geographically dispersed and to place goods competitively in markets far from their domestic borders" (*10*). For the purpose of this paper, soybeans will be considered as the raw material in question in such definitions. Although business logistics is divided into four key activities, (*a*) cooperation of customer service standards with marketing, (*b*) transportation, (*c*) inventory management, and (*d*) information flows and order processing (*10*), this paper focuses specifically on the impact of transportation decisions that Ballou cites as "some of the most important that face the logistician."

Buyers and sellers work in conjunction to complete transactions in the international soybean market. This paper examines global operations and transportation as key activities of logistics in context of the soybean market. The functional definition of global operations used in this paper is that of Dornier et al., "Global operations involve the process of planning, implantation, and control of the flow and storage of, [among other things,] raw materials, [such as soybeans,] from the point of origin to the point of consumption" (*7*). For the purpose of this paper, a distinction is made between the terms "internal transportation," which encompasses all transportation within the domestic borders of the country on the way to the international market, and "freight cost," which encompasses all transportation costs incurred from a product's point of origin to its point of destination on the international market. Internal transportation forms only a portion of total freight costs in these global operations, as the soybeans are transported from domestic fields within the two respective countries to reach maritime ports or foreign borders.

A country's infrastructure has a large influence in the efficiency of its productive sectors in the global market. According to Ojima and Rocha, a country's transport segment can interfere in the efficiency of many sectors of the economy (*11*). A company's logistical policy can be limited to the choices that are made available by a country's infrastructure. Schnepf et al. (*5*) agree that infrastructure is one of the factors that contributes directly to the competitiveness of a commodity such as soybeans.

The efficient practice of logistics offers a competitive advantage to businesses. Competition is promoted by the improvement of transports: a business farther away from a client is still able to compete with a business closer to the same client if its costs are comparatively cheaper (*12*). Ballou supports this affirmation, stating that logistical decisions in the areas of transportation, customer service levels, and facility locations have an impact "on the profitability, cash flow, and return on investment of the firm" (*10*).

For the purpose of this paper, decisions in the area of transportation modes are examined. It is estimated that transportation costs alone compose between one- and two-thirds of all logistical costs. Transport decisions involve, among other things, "mode selection, shipment size, and routing and scheduling." (*10*). All of these decisions are influenced by the proximity of warehouses to customers and plants. Another point of interest in the international soybean market is intermodal transportation—the process of shipping a product via more than one transportation mode (i.e., a product arrives at a port via

maritime transport and is then transported by rail to its destination)—that has been driven principally by increased international shipping, which frequently involves multiple modes (*10*).

It is more advantageous to transport soybeans, a product of low aggregated value, by waterway or railway, thus taking advantage of the economies of scale of the great quantities that can be transported (*13*). Plá and Salib (*6*) offer the following evaluation of commodity transportation. "Railways and waterways are more adequate for the transportation of agriculture products due to the characteristics of the cargo and its respective movements in Brazil, or rather, large volumes with concentration in a few, short periods of the year, low quotients of value/freight of the products and long distances" (*6*).

Combining this information, a holistic vision of the reality of commodity transportation can be extracted. Soybeans, a common low-unit-value, high-demand product on the international market, often involve multiple modalities of transportation over long distances, and thus economically efficient high-volume transport is necessary to ensure competitive prices. In the following section, the role of soybeans in the Brazilian economy and the transport of the grain to the international market will be discussed, taking into account the previously discussed logistical concepts.

BRAZILIAN AND U.S. SOYBEAN TRANSPORTATION POLICIES AND ISSUES

Agriculture plays an important role in the Brazilian economy. According to statistics provided by the Brazilian Agricultural Ministry, Ministério da Agricultura, Brazil was the fifth most productive exporter of agricultural products in the world in 2004 (*14*). In terms of national impact, the agricultural sector in Brazil contributed 28%, or US$55 million, to the country's total gross domestic product (GDP) in 2008 (*15*).

Brazil is the second largest exporter of soybeans in the world, producing 27% of the world's soybeans in 2008 and 2009 and making up 38% of the crop's world export figures in the same time period (*2*). As Brazil's most exported agricultural product, soybeans make up a large part of the nation's agricultural GDP percentage. In 2007, unprocessed soybeans represented 29% of the total number of Brazilian agricultural exports. Soybeans and all of its derivatives combined (including soybean crush and oil) contributed to 48% of the country's agricultural exports in the same year. These data can be seen in Figure 2 (*16*). Thus, a strong connection can be seen between economic gains and international soybean trade.

Historically in Brazil, the most often used means of cargo and goods transportation has been via roadway. According to Dias (*17*), at the end of the 1980s, 76.4% of the cargo transported within the country was transported on the road, in comparison with 14.2% by railway and 9.3% by waterway. Both railway and waterway transportation have seen gains in their frequency of use in the past two decades. The privatization and deregulation of the railways and ports and the elimination of export controls in the 1990s helped diminish the costs of these means of transportation (*5*), thus stimulating investment and refurbishment. These assertions are supported by the information offered by the Brazilian National Transport Confederation, Confederação Nacional de Transporte, 2009 statistics bulletin. In 2009, the percentage of roadway cargo transportation dropped to 61.1% and the percentage of both railway and waterway cargo transportation increased to 20.7% and 13.6%, respectively (*18*). These data can be seen in Figure 3.

Moreover, the Brazilian tendency to transport by truck is extremely relevant to the transport of soybeans because Brazilian soybean farmers frequently opt for truck transportation instead of using cheaper modes of transport, such as railways and waterways. According to Schnepf et al. (*5*), these elevated costs incurred in truck transportation are caused by inefficient and underdeveloped waterway and railway systems.

Brazil possesses almost 30,000 km of functional railways (*5, 17*). However, Dias (*17*) holds that the lack of a uniform rail gauge is caused by the low use of the Brazilian railway system in transport, among other factors. There are three types of railway gauges: metric, 99 cm, used in 65% of the country; wide, 160 cm, used in 17% of the country; and the mixed gauge, which accommodates both other gauge types (*2*). These inconsistencies imply challenges to railway transportation.

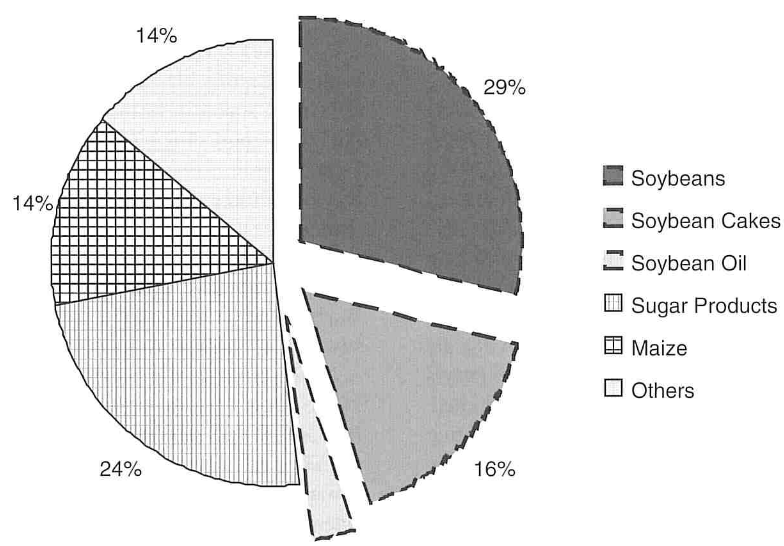

FIGURE 2 Brazilian agricultural exports. 2007. (Source: *FAO-STAT Agriculture, 2007*, Food and Agriculture Organization, United Nations, 2007.)

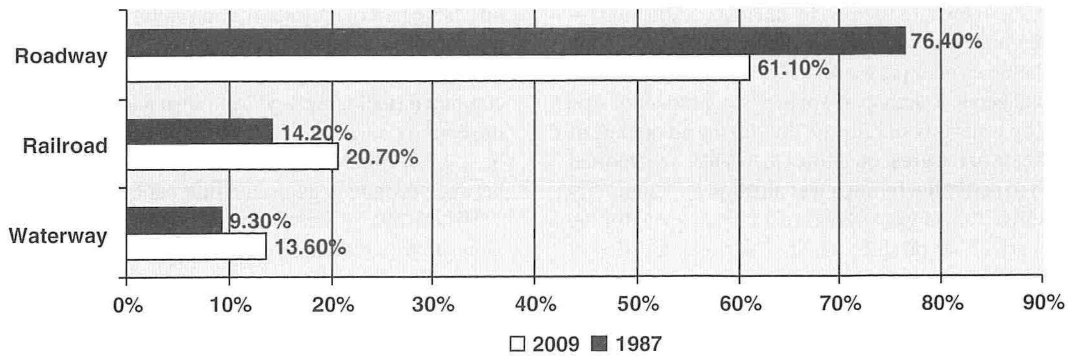

FIGURE 3 Cargo and goods transportation tendencies in Brazil in 1987 and 2009. (Source: Dias, M.A.P., *Transportes e Distribuição Física*, 1987, and *Boletim Estatístico*, Confederação Nacional de Transporte, 2009.)

As mentioned in the theory section, Dornier et al. (*7*) assert that the storage of a product is directly related to its transportation policy. In Brazil, the lack of adequate storage centers along the soybean transportation chain stands out as a weak spot in the transportation scheme, principally in waterway ports and railway stations (*5*).

According to Schnepf et al. (*5*), because of the perishable nature of soybeans, the lack of satisfactory storage centers such as silos causes Brazilian exporters to push soybeans onto the international market in undesirable seasons when the prices are relatively low. The lack of sufficient storage contributes to the crop's exposure to negative factors such as the elements and rodents, diminishing the product's quality before even reaching the buyers. The resulting rush to transport soybeans has reportedly contributed to enormous lines of trucks waiting for multiple days to load and then transport soybeans to ports.

In the past three decades, the epicenter of Brazilian soybean production has migrated to the interior states of Mato Grosso and Mato Grosso do Sul. This rapid growth in soybean production levels has exceeded the rate of the region's infrastructure expansion, as the poorly developed transportation infrastructure (*19*) is still in the process of development (*9*).

Because of the poorly developed infrastructure, Brazilian soybeans face an arduous journey on the way to the international market, from the fields of Mato Grosso and Mato Grosso do Sul along the states' less-than-satisfactory, often unpaved (*9*), road system to the most-used Brazilian ports of Santos, Paranaguá, and Rio Grande. These journeys are from 1,500 km to 2,200 km in some cases. As of 2003, Mato Grosso (a state roughly the size of the U.S. states of North Dakota, South Dakota, Nebraska, Iowa, and Minnesota combined) possessed just one paved roadway (BR-364), which crossed the state in an east–west direction. Some advances are being made to help reduce transportation costs. Plans are underway for the extension of the highway system in the interior soybean-producing regions, and the development of the railroad line, Ferronorte, has managed to link the southern reaches of the soybean-producing regions to the country's busiest Atlantic port, Santos. However, waterway options are limited. Many of the rivers in the region flow from south to north, eliminating the possibility of cheaper barge transport to the important Atlantic coast ports (*19*).

Ojima and Rocha (*11*) assert that the railway and waterway systems in Brazil still are not sufficient to realize the transport of grain in many cases, making the use of roadway transportation necessary, even when faced with long distances. As previously mentioned, soybeans are a low-aggregated-value commodity and trucks are not a cost-efficient means of transportation because of the high volume that must be carried to achieve sufficient economies of scale. A truck loads around 150 times fewer soybeans than a railway composition and around 600 times less than a barge.

Barges have come to be used on the Madeira River (*11*), where soybean producers took it upon themselves to create a route from Mato Grosso and Mato Grosso do Sul (roughly 950 km), trucking the soybeans to the port to be ultimately transported down the Amazon River to an export facility in Itacoatiara, in northern Brazil (*19*). Completion of this project would provide a natural trajectory and shorter distance from Itacoatiara to the European and Asian markets via the Panama Canal (*4*), compared with the ports located in southern Brazil.

The influence of the cost accumulated in roadway transportation in the final landed cost of the soybeans can be seen in the following example. As mentioned before, the largest soybean-consuming markets are China and the European Union. In the following example, the busiest port in the Chinese market, Shanghai, is used as the examined destination.

The distance from Sorriso, Mato Grosso, to the most-used port in Brazilian soybean transportation, Santos, is 1,190 mi (1,904 km). In 2007 and 2008, the transport cost from Sorriso to the ports of Shanghai, China, through the mentioned ports represented 31% to 34% of the total landed cost of the soybeans (*2*).

A difference can be seen in the total landed cost to the final consumer when this logistical situation is compared with that of Cruz Alta in the state Rio Grande do Sul, Brazil. The distance from Cruz Alta to the port of Rio Grande is 288 mi (463 km), and the corresponding transportation costs to the same ports are almost reduced by half, falling to 16% to 19% of the landed cost (*2*). "From a logistical perspective, soybean production located within a small radius of these ports (Santos, Paranaguá, and Rio Grande) remains highly competitive with U.S. soybeans in European markets. However, as Brazilian production moves into the interior, the high cost of getting soybeans to market erodes competitiveness" (*5*).

Implications of the previous assertion can be seen in Table 1, which compares transportation costs from Sorriso and Cruz Alta, Rio Grande do Sul, with transportation costs from Davenport, Iowa, (*2*). The port in question for Davenport is located at the mouth of the Mississippi River in the Gulf of Mexico. The destination port considered is located in Shanghai, China. All "to port" distances are considered as distances traveled within domestic borders.

Table 1 includes an analysis of U.S. dollars per metric ton and U.S. dollars per 100 mi. In accordance with the figures presented in Salin (*2*), U.S. internal transportation was identified as more efficient

TABLE 1 Transportation Cost Comparison in $USD/Metric Ton and $USD/Kilometer from Sorriso, Mato Grosso, Cruz Alta, and Rio Grande do Sul, and Davenport to Shanghai

	Davenport, Iowa, United States, 1,343 mi to Port		Sorriso, MT, Brazil, 1,190 mi to Port			Cruz Alta, RS, Brazil, 288 mi to Port		
Year	U.S. Dollars per Metric Ton	U.S. Dollars per 100 mi	U.S. Dollars per Metric Ton	U.S. Dollars per 100 mi	Difference (%)	U.S. Dollars per Metric Ton	U.S. Dollars per 100 mi	Difference (%)
2007	155.35	11.57	180.51	15.17	+31	93.55	32.48	+181
2008	133.09	9.91	186.12	15.64	+58	94.37	32.77	+230

NOTE: 1 mi = 1.61 km; MT = Mato Grosso, RS = Rio Grande do Sul.
Source: Salin, D. L., *Soybean Transportation Guide: Brazil 2008,* and Agriculture Marketing Service, U.S. Department of Agriculture, 2009.

and, therefore, was used as a market benchmark for comparison in this study. Brazilian soybean transportation costs were then compared with the U.S. benchmark to obtain a relative perspective, in percentage form, of soybean costs in the two countries. Between 2007 and 2008, transportation costs from Sorriso to Shanghai showed themselves to be, on average, 44% higher than that of U.S. transportation costs. More noticeable was the comparison with Cruz Alta, Rio Grande do Sul, where, although maintaining a lower cost due to proximity to major shipping ports, a steep peak is shown in the proportion spent on internal transportation. Between 2007 and 2008, transportation costs from field to port were shown to be around 205% more expensive than that of the U.S. benchmark. Davenport is located some 1,055 mi farther from port than Cruz Alta, Rio Grande do Sul.

U.S. soybean transportation policies differ from those of Brazil. However, U.S. soybean production, in general, should be examined. As the world's leading soybean-producing nation, the United States produces 38% of the world's soybeans and makes up 45% of the soybean export trade (*2*). The internal soybean transportation structure in the United States differs from that of Brazil in that it depends more on railway and waterway systems for the commodity's mass transport. U.S. farmers enjoy an efficient and low-cost transportation system because they do not rely too heavily on any one specific mode of transportation. The equilibrium of competition and integration between barge, railroad, and truck transportation facilitates a low-cost system (*13*). For example, soybeans harvested in the interior of the country can be transported by rail to the Mississippi River in St. Louis, Missouri, where they can then be loaded onto a barge and shipped southward to the port in Louisiana.

Truck transportation dominates the total U.S. agricultural transportation modal share, accounting for 70% of all agricultural products moved (including fresh produce, milk, sugar, live animals, bakery products, processed vegetables, and fruits). However, truck transportation accounts for just 40% when viewing transportation in the context solely of the grain and seed market, with rail and water representing 27% and 29%, respectively, of the modal share.

Overall, according to the Agricultural Marketing Service's report, *Transportation of U.S. Grain from 1987–2006,* featured in the USDA and U.S. Department of Transportation's 2010 report (*13*), railways and waterways constituted 37% and 57% of U.S. soybean export transportation, while roadway transportation by truck accounted for just 6% of the grain's movement. The same report concludes that "rail and barges lend themselves to bulk and lower-value products such as wheat and soybeans . . . The higher ratio of ton-miles for rail and barge indicates their efficiency at moving commodities long distances, such as moving grains and oilseeds to ports for export."

According to Schnepf et al. (*5*), the United States has a widespread network, centered around the Mississippi River and its tributaries, which makes for economic and efficient commodity transport of products such as soybeans to the international markets via barge. The authors assert that the American barge system is "unrivaled as the most economic and efficient manner of transport of commodities from the field to the international market."

The United States also possesses almost 150,000 mi (240,000 km) of usable railway, eight times that of Brazil, giving U.S. soybeans a competitive edge in transportation (*2, 5, 13*). A uniform gauge system offers a competitive advantage to the United States, because transporting along a multiple-gauge system requires expensive stops, and the uniform system also facilitates the movement of equipment. Moreover, because of the heavier rails of American trains, the locomotives and train cars are able to transport larger densities of the crop, thus gaining an advantage in economies of scale (*5*).

Taking these modes—highway, port, rail, or waterway—and others into account simultaneously, a view of the potential for intermodal grain transportation within the United States can be seen. According to statistics from the U.S. Department of Transportation presented in Vachal and Reichert (*20*), there are more than 2,695 intermodal facilities in the United States, providing more flexible access to producers and buyers. These facilities also play integral roles in containerized commodity trade, which adds value to agricultural products such as soybeans through their ease of transition between modes of transportation in international trade (*20*).

In the United States, the convenient location of agricultural storage facilities—mainly grain elevators and warehouses—has played a key role in the development of commodity trade. The efficient system helps in the prevention of spoilage and infestation by rodents and insects and contributes to a reduction in transportation costs. This extensive storage system also helps to gather large amounts of crops, which can then fully supply barges used in waterway and international trade (*13*).

A difference in the transportation tendencies between the two leading soybean-producing countries can be seen when considering the following example. In the case of American soybean exports to Mexico, which can be accessed by roadway, railway, and waterway, the most-used method is railway, representing 61% of such exports to Mexico. Maritime transports and trucks represent 31% and 8%, respectively (*21*). Basically inverting the Brazilian model of soybean transportation, the example demonstrates a large break from the Brazilian tendency to transport soybeans via roadways, which is considered more costly in commodity transportation.

Figure 4 shows data from the comparison Schnepf et al. made of soybean's accumulated landed cost from the principal U.S. and Brazilian soybean-producing regions. Once again, in accordance with the figures presented in Schnepf et al. (*5*), U.S. production, internal transportation, and freight tariffs were used as optimal market

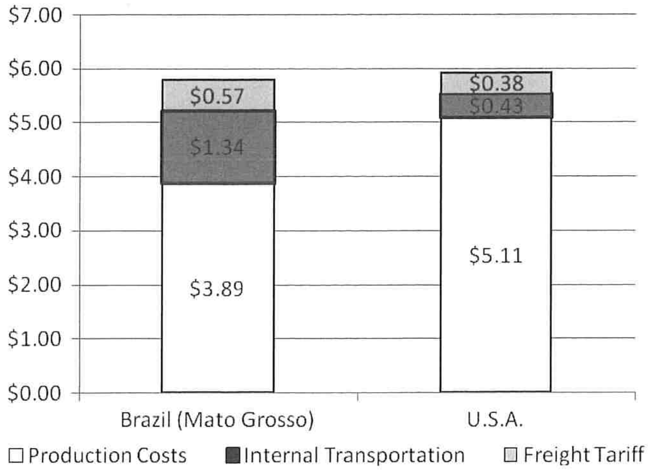

FIGURE 4 Brazilian and U.S. soybean cost comparison in US$/bushel (1 bushel = 0.021772 metric ton). (Source: Schnepf, R. D., Dohlman, E. and Bolling, C., *Agriculture in Brazil and Argentina: Developments and Prospects for Major Field Crops*, and *Agriculture and Trade Report*, U.S. Department of Agriculture, 2001.)

benchmarks for price comparison. The respective Brazilian costs were then compared with the U.S. benchmarks to obtain a relative perspective, in percentage form, of how soybean costs vary between the two countries. Internal transportation is considered as transportation within domestic borders.

Even though it has a higher accumulated farm-level production cost among its global competitors, the United States maintains a position of leadership in the world market through economically efficient means of transportation. In 2001, in the principal areas of production in Brazil, soybean cultivation and harvest ran at a considerably lower cost, representing just 76% of the U.S. production benchmark costs. Freight tariffs were 50% higher in Brazil, representing a difference of just US$0.19 per bushel. However, as can be seen by the graph, the United States recovers much of its competitive edge through relatively low transportation costs (*5*). This comparison exhibits, while maintaining consistency with figures from more recent studies (*2*), that Brazilian transportation costs are around 211% greater than those of the United States.

The average cost of transport from the midwestern United States to Shanghai is, on average, 20% of the landed cost, compared with 31% to 34% from Mato Grosso, Brazil, to the same ports (*2*). These reductions in transport costs are reflected in the cost to the final consumer, thus aiding the competitiveness of U.S. soybeans on the international market.

CONCLUSIONS

This paper has examined the roles of transportation policies as a key activity of logistics in the international soybean market. Specifically, the Brazilian and U.S. transport systems were compared, drawing upon statistics, transportation, and logistics theory.

Until Brazil improves its means of transportation, Brazilian soybeans will be more subject to the fluctuations in the world petroleum market than American soybeans. A jump in gas prices will affect Brazilian soybean competitiveness more profoundly than that of the United States because of the disproportionally larger transport costs from production regions to the ports in Brazil—costs that are tied to its dependence on truck transportation.

However, some significant changes have been undertaken to improve Brazil's ability to move large amounts of its most profitable commodity at a low cost. Soybean transportation via navigable rivers has been developing in recent decades, aiding in the decrease of transportation costs. Waterway projects, such as the Tiete-Parana and Madeira river waterways, have helped improve a more economic transportation of the crop. Such waterway transport systems are similar to those of the United States, and if development continues they can contribute positively to the increased competitiveness of Brazilian soybeans. One long-term forecast to the year 2025 indicated that development of river transportation in northern Brazil will help Brazilian soybean exports grow by more than 200%, from 7 to 17 million metric tons. Several undertakings can be credited with the projected jump in exports. A project to develop an interior water–truck shipment system to Itacoatiara and Santarem (a port facility opened in 2003) and a government project to improve highway BR-163 are expected to result in the reduction of shipping costs and in the increase in economic appeal of exporting soybeans rather than selling them domestically as feed stock for cattle and livestock. Decreases in historically high shipping costs will also persuade local farmers to plant soybeans, thus increasing overall production (*4*). A serious undertaking of infrastructure creation and refurbishing projects based along Brazilian railways and waterways could enable this significant growth to occur, as evidenced by the increases in usage of railway and waterways after the privatization of such projects (*17*, *18*).

Apart from large, state-sponsored infrastructure undertakings, there are many opportunities for profits to be made by private-sector transporters in reducing the cost of soybeans in Brazil as well. Freight consolidation could be achieved through various measures. Increasing the capacity and number of storage points would enable soybean suppliers to meet demand with larger, more consolidated shipments. Increasing storage capacity with larger and a greater number of silos will also help eliminate the temporal pushes that Brazilian soybeans suffer in order to avoid product deterioration from rodents and the elements, also giving suppliers more opportunity to strategically coincide their transactions with favorable market fluctuations. Continuing to develop waterway systems in Brazil will enable vehicle consolidation through the use of larger barges to push increasingly larger amounts of soybeans down its vast river system, rather than relying upon roadway transportation, which has shown itself to be more costly and less efficient. In the literature, many authors agree that Brazilian soybeans suffer increases in price along the way to the international market because of its comparatively high costs in the internal transportation sector. The same authors agree that improvement in the area of transports and their use would bring about a lowering of the cost of soybeans to the final customer (*2, 5, 6, 9, 11, 19*). From the figures presented in this study and previous studies, it can be seen that transportation costs are a major competitive differential in the global soybean market, as Brazilian soybeans suffer from much higher transportation costs, representing, in some cases, 230% more than U.S. transportation costs (see Table 1).

These elevated transport costs are transferred to buyers, thus raising the landed cost of soybeans, Brazil's leading agricultural export, and influencing the grain's performance and competitiveness on the international market. The refurbishment, investment in, and creation of efficient means of commodity transportation will enable Brazil not only to continue being a big player in the world soybean market but perhaps the biggest.

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Overall Impacts of Off-Hour Delivery Programs in New York City Metropolitan Area

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This paper examines the chief findings of research conducted on policies to foster off-hour deliveries (OHDs) in the New York City metropolitan area. The goal was to estimate the overall impacts of eventual full implementation of an OHD program. As part of the research, a system of incentives was designed for the receivers of deliveries the system combined Global Positioning System (GPS) remote sensing monitoring with GPS-enabled smart phones to induce a shift of deliveries to the off-hours from 7:00 p.m. to 6:00 a.m. The concept was pilot tested in Manhattan by 33 companies that switched delivery operations to the off-hours for a period of 1 month. At the in-depth interviews conducted after the test, the participants reported being very satisfied with the experience. As an alternative to road pricing schemes that target freight carriers, this was the first real-life trial of the use of financial incentives to delivery receivers. The analyses indicate that the economic benefits of a full implementation of the OHD program are in the range of $147 to $193 million per year, corresponding to savings on travel time and environmental pollution for regular-hour traffic as well as productivity increases for the freight industry. The pilot test also highlighted the great potential of unassisted OHD—that is, OHD made without personnel from the receiving establishment present—because almost all participants who used this modality decided to continue receiving OHD even after the financial incentive ended.

The research conducted on the urban delivery industry's response to freight road pricing (*1*) produced findings that challenged long-held assumptions. It showed that (*a*) the ability of carriers to unilaterally change delivery times is limited because it necessitates the concurrence of the receivers (who tend to prefer regular-hour deliveries to take advantage of the staff at hand), and (*b*) cordon tolls are not likely to be effective in inducing a switch to the off-hours because most segments of the urban freight industry cannot pass toll costs on to their customers, depriving them of the price signal needed to effect a change. The data from the Port Authority of New York and New Jersey indicate that (*a*) only about 9% of carriers would be able to pass the toll costs on to their customers and (*b*) when carriers were asked about why they did not change behavior in response to time-of-day tolls, about 70% of them cited customer requirements as the reason (*1*). In essence, the receiver is the key decision maker.

Further analyses (*2*) concluded that the difficulties that carriers have in passing cordon time-of-day tolls to their customers reflect a highly competitive market with delivery rates equal to marginal costs. Because the cordon toll is a fixed cost (does not depend on the unit of output), it does not enter into the rates. The empirical data confirmed that only the market segments with market power (i.e., carriers of stone–concrete, wood–lumber, food, electronics, and beverages) could pass toll costs on in a meaningful way (*2*). The key insight is that, because the price signal only reaches the receivers in those cases where the carrier has market power (although in a diluted fashion because the toll costs are allocated among multiple receivers in the tour) and receivers have no incentive to change behavior, carrier-centered pricing policies are not as effective as they need to be. It follows that new policy paradigms are needed to specifically target the receivers to induce them to switch to the off-hours. The effectiveness of these policies has been established by previous behavioral research (*3, 4*).

The fundamental tenet of this paper is that the key to inducing a shift of truck traffic to the off-hours is to convince receivers to accept off-hour deliveries (OHDs) by either providing incentives in exchange for their commitment to OHD or by fostering the use of concepts such as unassisted OHDs that do not require receivers to provide staff to handle deliveries during the off-hours. Because carriers stand to benefit from doing off-hours work, they would be glad to do OHDs as long as a sufficient number of receivers are willing to accept OHDs (*5*). Such deliveries are 20% to 30% cheaper than regular-hour deliveries and lead to much-reduced parking fines, which average $500 to $1,000 per truck per month for regular-hour work in New York City. Inducing receivers to accept OHDs would (*a*) remove the barrier that prevents many carriers from doing OHDs,

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(*b*) lead to a significant shift of truck traffic to the off-hours, (*c*) reduce congestion and improve environmental conditions, and (*d*) enhance the competitiveness of the urban area by promoting more productive and efficient business activities.

This paper looks at the chief findings of a research project funded by the U.S. Department of Transportation's Remote Sensing Program that estimated the overall impacts of an eventual full implementation of an OHD program and the results of the first real-life trial of the use of financial incentives to receivers as an alternative to road pricing schemes that target carriers. The paper provides a succinct account of the results from the OHD pilot test, the anticipated economic impacts of a full implementation of the program, and a summary of key findings. Other publications discuss the technical details of the modeling and economic research conducted (*2–4, 6, 7*).

PILOT TEST RESULTS

The OHD pilot test was organized around three industrial partners: (*a*) Foot Locker and New Deal Logistics; (*b*) Sysco and a sample of its customers; and (*c*) Whole Foods Market and a sample of its vendors. In all cases, these partners switched their distribution chains to the off-hours for at least a month. In total, about 25 receivers (30 receivers, counting partial participation) and eight carriers–vendors participated in the test. About half of the receivers conducted staffed OHD, where staff were present to accept deliveries; the other half chose unassisted OHD, where the receivers gave delivery drivers store keys. Since there were no interactions among the industrial partners, the pilot tests were run independently of each other. These partners committed a significant amount of effort as high-level executives, in some cases having their entire logistics teams participate in dozens of conference calls to discuss preparations for the pilot test. Although the research team gave the partner carriers a token $3,000 payment as a show of appreciation, this covered not even a fraction of their staff time. Their investment in this effort provides clear evidence of the industry's support for the concept.

For successful participation in the pilot test, the participating receivers were provided a financial incentive of $2,000 to compensate for the setup costs associated with switching from the regular to the off-hours at the beginning of the pilot, and then back to the regular hours upon completion. The rest of the carriers, because they stood to benefit from OHD, were given smaller incentives of $300 per truck to compensate for the corresponding setup costs while participating in the pilot test.

Data Collection Scheme

The remote sensing component was undertaken using the Global Positioning System (GPS), GPS-enabled smart phones, and the Copilot|Live turn-by-turn navigation software. The smart phones were configured so that the only action required by the driver was to turn the phone on at the beginning of the route; no further interaction between the driver and the smart phone was required while driving. Safety was the utmost concern, and the research team ensured that the smart phone would not be a distraction to the driver. Usage and safety information was provided when the phone was delivered. In cases where the companies already had GPS equipment, they were given the option of sharing their own data with the research team instead of using the phones. A noticeable number of participants elected to do that, and some even provided data for the entire metropolitan area, not just those involved in the pilot test. This enabled the team to obtain background performance data for a much larger fleet of trucks. In some cases, passive GPS data loggers were used as backup. The research team analyzed the data to obtain estimates of travel speeds, delays, standard deviations, and other performance measures.

Productivity Impacts

This section examines the results obtained during the pilot test, contrasting them with the base case conditions in terms of productivity. The productivity analyses focus on the travel speeds (from depot to first customer in Manhattan and from customer to customer) and the service times (time spent at a given location making deliveries). The travel to the first customer was separated from the customer-to-customer trips because they have different characteristics (the former is a relatively long trip with few stops in between, while the latter are typically short trips with many stops for signals, pedestrians, etc.). The estimation of service times (the amount of time a truck stays at a customer location) was important because it provides key insight into the delays associated with making deliveries. Because the data from the different groups in the pilot test were not enough to produce statistically representative results for the entire range of times of travel, the different data sets were pooled together to produce a more robust set of estimates. The speeds represent space mean estimates—the distance travel from a point of origin to a point of destination divided by the time it takes to make that trip. Instantaneous speeds are not used because they exhibit a great deal of variability and cannot capture the traffic obstructions. A companion paper discusses customer satisfaction (*8*).

The data show that there are significant increases in travel speeds from the depot to the first customer in Manhattan. For example, the data for Group 1 (Foot Locker–New Deal Logistics)—probably the most complete for this analysis—indicate that the average travel speed in the a.m. peak is 11.8 mph. In contrast, during the off-hours (7:00 p.m. to 6:00 a.m.) it increases to 20.2 mph, for a travel speed increase of 71%.

For customer-to-customer travel speeds in Manhattan, the results are equally significant. It should be mentioned, however, that there are almost no data for the time between 10:00 p.m. and 5:00 a.m. (the 4:00 to 5:00 a.m. time period contains only a handful of observations). Similarly, although the entire data include about 4,000 individual trips, no one can tell whether they are representative of the overall truck traffic in the study area. In spite of these caveats, the data do provide a coherent picture of the potential impacts of OHD. The results are displayed in the form of a box-and-whisker plot that presents the second, 25th, 50th, 75th, and 98th percentiles and the outliers. In the plot, the second percentile is the tip of the lower whisker, the 25th percentile is the lower tip of the box, the 50th percentile (median) is the line between the boxes, the 75th percentile is the top of the box, and the 98th percentile is the tip of the upper whisker. Values outside these percentiles are shown as crosshatches.

The customer-to-customer speeds and their percentiles are shown in Figure 1. The results indicate a clear pattern of speeds decreasing during the day hours and increasing during the off-period. As illustrated in Figure 1, while speeds reach almost 8 mph during the 5:00 to 7:00 a.m. time period, they drop to below 3 mph in the day

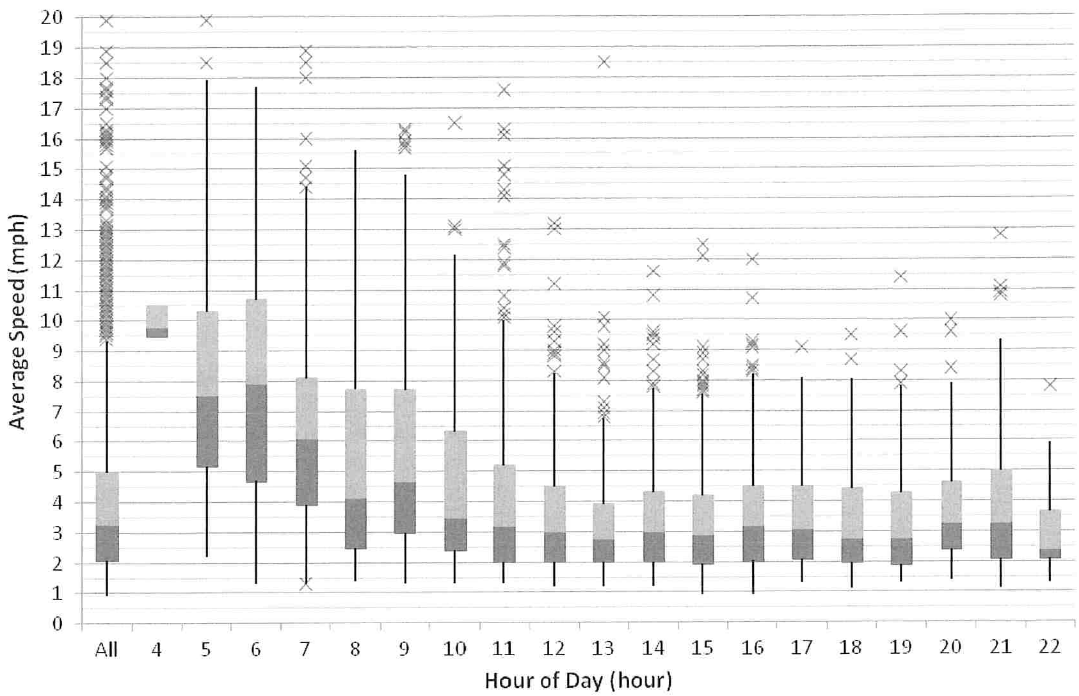

FIGURE 1 Customer-to-customer space mean speeds by time of day.

hours. The sparse data in the 4:00 to 5:00 a.m. time period (only four observations) suggest that during the early hours of the day, travel speeds could be much higher. It is worthy of mention that different parts of New York City exhibit different speed distributions. The results indicate that a truck traveling for 10 mi making deliveries could save 1.25 h of travel time if the average speeds are assumed to be 8 mph during off-hours and 4 mph during regular hours. Obviously, the longer their tours, the larger the economic savings associated with a switch to the off-hours.

The second performance measure is the service time, the time spent by the driver at the customer location. This includes the amount of time that the driver spends loading and unloading the cart used to transport the cargo, walking to and from truck and to and from customer location, finding person to accept delivery, waiting for authorized individual to review the shipment, waiting for proper signatures and payment, sorting out any problems that arise, and other related activities. Figure 2 shows the estimates produced by the research team, with service times increasing during day hours and decreasing during the off-hours. While during the morning hours—when the bulk of the deliveries are made—service times consistently exceed an hour, reaching a maximum of 1.8 h during the 10:00 a.m. to noon period, they drop to about half an hour during the night hours. Although no one knows how representative these numbers are of industry-wide conditions, they do indicate that carriers could save significant amounts of time when they switch from the morning to the night hours.

It is important to mention that the authors discussed the results shown in Figure 2 with the industrial partners to assess their validity. The partners indicated that these results do represent the realities observed on the ground, which they deem part of the ". . . cost of doing business in New York City. . . ." They explained that during the day hours, drivers typically are forced to park two to three blocks away from the customer location, have to wait for loading docks, experience delays in getting access to elevators (either because of other deliveries or building visitors), have to move their trucks to other locations to avoid fines, and have to serve multiple customers from the same location (which necessitates long walks in some cases) to reduce the hassle of moving the truck and finding parking. In contrast, during the off-hours they park closer to the customers, causing all the other issues to diminish or disappear altogether. The authors also asked about delivery sizes during both regular and off-hours and were told that during off-hours shipment sizes tend to be larger than during regular hours because carriers take advantage of the larger productivity to transport more cargo. The implication is that once the larger shipment sizes during the off-hours are factored in, the productivity savings associated with reductions in service times are likely to be larger than suggested by Figure 2.

These findings have major economic implications. The most obvious one is that reducing service times will increase the profitability of delivery operations and ultimately lower the cost of the products consumed in New York City. For instance, a delivery truck that saves 15 min at each of six deliveries (about the average in New York City) will save a total of 1.5 h. Regardless of the assumption made, the economic savings are substantial and potentially larger than the travel time savings attributed to faster speeds during the off-hours.

At the end of the pilot test, the research team conducted in-depth interviews with the participants, who reported to be very satisfied with the experience. Receivers indicated that they liked most the reliability in OHD, where uncertainty was removed about when the delivery was going to actually arrive. Carriers considered increased productivity and less stress on the driver the most positive features of OHD. The results of these interviews and the satisfaction surveys conducted are reported in a companion paper (*8*).

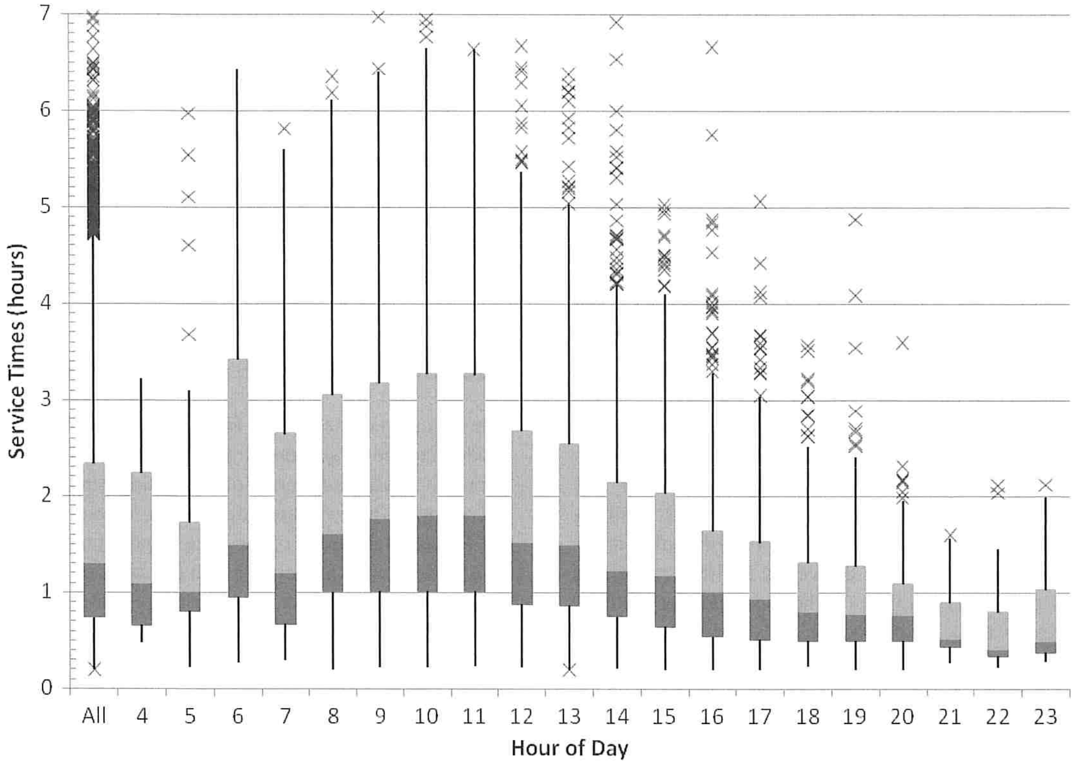

FIGURE 2 Service times by time of day.

Upon termination of the incentive at the end of the pilot study, all receivers who staffed OHD reverted to regular-hour deliveries. However, 90% of the receivers who tried unassisted OHD have continued with the practice, to the great delight of the carriers. This provides an indication of the potential of unassisted OHD; with minimal public sector intervention to induce receivers to try it, it may be possible to convince them to use it on a permanent basis.

IMPACTS OF FULL IMPLEMENTATION

The quantification of the impacts of a full implementation of an off-hour delivery program required (*a*) the quantification of the total number of truck-trips that would switch to the off-hours in response to a given financial incentive and (*b*) the use of network models to quantify the impact of several scenarios of shifts to the off-hours on the entire network. This section succinctly describes the process that followed and the chief results obtained.

The estimation of the potential participation in OHD required a two-step process involving estimating the market response to financial incentives and quantifying the number of deliveries generated by the various industry segments (*9*). The estimation of the market response to the receivers' financial incentive was done using a behavioral microsimulation (*7*) and an analytical model (*10*) specifically designed for the purpose that produced similar results. Based on the behavioral research conducted, these models estimate how many receivers in the simulated delivery tours would switch to the off-hours, they simulate the response of the corresponding carriers, and they aggregate the results for the various industry segments. The next step was to quantify the total number of deliveries made by the various industry segments to compute the impacts of OHD on the transportation network. As part of this process, the research team

- Postprocessed the survey data collected to estimate freight trip generation models,
- Used the models to estimate the total number of deliveries by industry segment and ZIP code for the Manhattan area,
- Computed the number and percentage of deliveries that would switch to the off-hours for each ZIP code, and
- Used these estimates to modify the inputs to the regional travel-demand model [best practice model (BPM)] and a mesoscopic traffic simulation model developed by the research team.

The analyses revealed the following:

- A large number of freight deliveries are made to Manhattan. The estimates—based on the freight generation data collected—show that about 113,000 freight deliveries are made to Manhattan for an average trip rate of 0.163 freight deliveries per employee, or 2.798 freight deliveries per establishment. Reflecting the consumer nature of the area, the industry segments with the largest share are consumer goods, with 54.48% (wholesale and retail), and the food sector, with another 24.28% (eating and drinking establishments and food stores).
- The best candidates for participation in OHD are the food and consumer goods sectors. On the basis of the total number of deliveries generated and the inclination of each industry segment to participate in OHD, the research team concluded that the best targets are the food and consumer goods sectors. The team estimates that

financial incentives of $5,000 to $10,000/year would switch approximately 7% to 15% of the truck trips to the off-hours, representing 7,000 to 16,000 truck trips/day.

- Large traffic generators (LTGs) generate about 4% to 8% of the total number of freight deliveries in Manhattan. The research team estimated that the 88 buildings with their own ZIP codes (e.g., Empire State building) generate about 4% of the total freight traffic in Manhattan. If the buildings without their own ZIP codes (e.g., Grand Central Terminal) and the large establishments with more than 250 employees are added, they would generate 4% to 8% of the total truck traffic. More importantly, because the LTGs tend to have their own centralized delivery stations, they could receive OHDs and then deliver the cargo to the consignees during regular hours without inconvenience to the actual receivers.
- Unassisted OHD are a very cost-effective alternative. "Unassisted OHD" refers to a range of systems that eliminate the need for human intervention at the receiving end. Examples include (*a*) "key deliveries" in which the receiver gives a key to the carriers, enabling them to deposit the goods in the store; (*b*) the use of double doors that enable the driver to deposit the deliveries in the secured area with a key provided by the customer; (*c*) the use of delivery lockers in which a delivery is made to an electronically controlled cabinet at which the consignee retrieves the goods during the regular hours; and (*d*) the implementation of two-stage delivery systems in which supplies are transported during the off-hours and stored at a container, or storage pod, at a convenient location (e.g., a secured parking lot), from where staff can retrieve needed goods using small and environmentally friendly vehicles, among other configurations. Regrettably, there were no behavioral data that could be used to assess how willing the various industry segments would be to participate in unassisted OHD.

Next, the team estimated the traffic impacts of alternative OHD scenarios with the assistance of both a regional travel demand model (New York Metropolitan Transportation Council's BPM) and a mesoscopic traffic simulation model of an extracted network focusing on Manhattan. In doing this, the team

- Obtained the BPM and up-to-date hourly volume data from New York–area transportation agencies to calibrate the models,
- Extracted a Manhattan subnetwork for more detailed mesoscopic simulation and analysis,
- Simulated several scenarios of potential traffic shifts in both traffic models, and
- Compiled and analyzed the impacts to the traffic network predicted by both models, using a postprocessor developed by Ozbay et al. (*11*) to compute environmental impacts.

The extensive traffic simulation effort produced solid estimates of the impacts to Manhattan and the rest of the metropolitan network. The most prominent results indicate the following:

- The proposed program has a net positive impact on the traffic networks of Manhattan and the entire New York City region over the entire day. Negative impacts to off-hour traffic conditions caused by increased commercial vehicle traffic are eclipsed by the benefits accrued during regular hours because of a reduced amount of commercial vehicles.
- Impacts are observed at both the local level in Manhattan and the entire metropolitan area. While most delivery trips in Manhattan originate within Manhattan (as part of a delivery tour), a significant number of freight trips originate outside Manhattan (from ports and warehouses). Therefore, the benefits from reduced truck traffic during the regular hours are observed throughout the entire metropolitan region.
- A 10% carrier participation in OHD in Manhattan would produce a reduction of more than 6% in travel times on Manhattan links during regular hours. When averaged with the increase in travel times during the off-hours, this translates into an overall reduction of 4% in Manhattan link travel times. Estimates for other scenarios were produced.

ECONOMIC ANALYSES OF ALTERNATIVES

The team used the results from both the BPM regional network model and the mesoscopic traffic simulation (MTS) to estimate the economic impacts in terms of travel time savings and air pollution reductions. The estimates are based on a composite value of time (VOT) and valuations of the criteria pollutants. However, because of the uncertainty associated with the exact composition of the traffic in the entire network, the results are presented for different scenarios of composite VOT. Assuming a traffic composition of 83% passenger cars, 13% small trucks, 3% large trucks, and 1% buses; and values of time of $24 (which assumes an average occupancy of 1.2 passengers/vehicle), $35, $55, and $750 (VOT of passengers plus driver and vehicle) per vehicle class, respectively, leads to a composite value of $33.62/vehicle hour. Different assumptions lead to values as low as $25/vehicle hour, and as high as $40/vehicle hour. The analysis considers the following three cases:

- Financial incentives to food and retail sectors. This is the policy previously identified by the team as the most effective one—a financial incentive to receivers for accepting OHDs.
- Targeted programs aimed at LTGs. These policies focus on the major generators of truck traffic: large buildings that house scores of individual establishments, and large individual establishments in freight generation sectors with more than 250 employees.
- Unassisted OHD. These policies encourage OHD without the intervention of staff from the receiving establishment. These have great potential because they could lead to economic benefits comparable to those produced by the financial incentives, at a fraction of the cost.

The total benefits and costs for the stakeholders are shown in Tables 1, 2, and 3. Because there are no data about the incentive costs or the benefits in some of the alternatives, question marks have been added to the corresponding cells. For reference purposes, the values considered by the research team as the most likely ones have been shaded. These values correspond to $30/h for the composite VOT of roadway users and $40/h for the VOT for delivery trucks (large and small).

Table 4 and Figure 3 summarize the economic impacts for the case in which the composite VOT of roadway users is $30/h and the average value of time of delivery trucks is $40/h. As noted previously, the costs to receivers have been assumed to be equal to the total incentive cost (i.e., the incentive amount times the total number of establishments that accept it). This is a reasonable and conservative assumption because it provides an upper bound of the receiver costs (if the incentive amount does not cover the costs, the receiver would not accept it). As shown, the economic benefits to carriers and roadway users increase with receiver participation in

TABLE 1 Summary of Economic Impacts: Road Users

		Annual Benefit (millions)[a]								
		$20/h[b]		$25/h[b]		$30/h[b]		$35/h[b]		Public-Sector Incentive (millions)
	Trips Shifted	BPM[c]	MTS[d]	BPM[c]	MTS[d]	BPM[c]	MTS[d]	BPM[c]	MTS[d]	
Financial Incentives to Food and Retail Sectors and % of Total Truck Traffic Shifted										
$5,000 (6.49%)	7,262	$38.61	$20.68	$47.89	$23.95	$57.10	$27.23	$66.34	$30.51	$0.00
$10,000 (14.10%)	15,982	$57.58	$51.23	$70.96	$58.74	$84.42	$66.25	$97.84	$73.76	$0.00
$15,000 (20.90%)	23,617	$68.24	$65.50	$84.24	$76.11	$100.24	$86.72	$116.23	$101.94	$0.00
$50,000 (41.65%)	47,605	$139.21		$172.85		$206.49		$240.14		$0.00
Targeted Programs Aimed at Large Traffic Generators										
Large buildings[e]	8,345	$24.36	$17.68	$30.23	$21.28	$36.10	$24.87	$41.97	$25.18	?
Large buildings and 250+ employees[e]	17,878	$53.60	$26.86	$67.33	$32.84	$81.07	$38.82	$94.81	$41.87	?
Unassisted deliveries		?	?	?	?	?	?	?	?	?

NOTE: Question marks indicate an absence of data for incentive costs and benefits. The percent values next to the incentive amounts represent the percent of the total truck traffic that is shifted to the off-hours.
[a]Estimated based on changes to congestion, operating costs, noise, and air pollution assuming 250 days/year.
[b]Benefits (for passenger cars, buses, and trucks) depend on the composite value of time estimate used.
[c]BPM refers to best practice model, and the benefits are calculated for all links in the 28-county NYMTC region.
[d]MTS refers to mesoscopic traffic simulation, and the benefits are calculated for links located only in Manhattan.
[e]Assume 100% participation in OHD.

OHD though their rate of growth decreases. The costs to receivers—and consequently the incentive costs—increase rapidly as it becomes more difficult for receivers to participate.

It is worthy of mention that, in general, the benefits to the carriers are smaller than the costs to receivers, which is what economic theory predicts (*2*). In this situation, the market left to its own devices will not reach the more preferable outcome (off-hour deliveries) because the carriers cannot compensate the receivers for their extra costs, and still themselves be better off. This market failure is what justifies public intervention via incentives or other policies.

The analyses of Table 4 and Figure 3 show that beyond the $17,500/year incentive, the total costs outweigh the benefits brought about by OHD. However, the optimal amount of incentive is in between $10,000–$15,000/year (14% to 21% of total truck traffic). Table 4 shows the marginal benefit–cost ratio, which measures the ratio of the increase in benefits brought about by a given alternative,

TABLE 2 Summary of Economic Impacts: Carriers That Shift to the Off-Hours

		Annual Benefit (millions)[a]								Public Incentive (millions)
	Trips Shifted	$30[b]	$35[b]	$40[b]	$45[b]	$50[b]	$55[b]	$60[b]	$65[b]	
Financial Incentives to Food and Retail Sectors and % of Total Truck Traffic Shifted										
$5,000 (6.49%)	7,262	$21.54	$25.13	$28.72	$32.31	$35.90	$39.49	$43.08	$46.67	$0.00
$10,000 (14.10%)	15,982	$47.40	$55.30	$63.20	$71.10	$79.00	$86.90	$94.80	$102.70	$0.00
$15,000 (20.90%)	23,617	$70.05	$81.72	$93.39	$105.07	$116.74	$128.42	$140.09	$151.77	$0.00
$20,000 (25.34%)	28,634	$84.93	$99.08	$113.23	$127.39	$141.54	$155.70	$169.85	$184.01	$0.00
$25,000 (29.07%)	32,856	$97.45	$113.69	$129.93	$146.17	$162.41	$178.65	$194.90	$211.14	$0.00
$50,000 (41.65%)	47,605	$141.19	$164.72	$188.26	$211.79	$235.32	$258.85	$282.38	$305.92	$0.00
Targeted Programs Aimed at Large Traffic Generators										
Large buildings[c]	8,345	$24.75	$28.88	$33.00	$37.13	$41.25	$45.38	$49.50	$53.63	?
Large buildings and 250+ employees[c]	17,878	$53.02	$61.86	$70.70	$79.54	$88.37	$97.21	$106.05	$114.89	?
Unassisted deliveries		?	?	?	?	?	?	?	?	?

NOTE: Question marks indicate an absence of data for incentive costs and benefits. The percent values next to the incentive amounts represent the percent of the total truck traffic that is shifted to the off-hours.
[a]Estimated based on changes to congestion, operating costs, noise, and air pollution assuming 250 days/year. Assume 0.80 h/tour saved due to faster speeds.
[b]Average value of time carriers that shift to off-hours.
[c]Assume 100% participation in OHD.

TABLE 3 Summary of Economic Impacts: Receivers and Public Sector

	Trips Shifted	Cost to Receivers (millions)[a,b]	Public Incentive (millions)[a,c]
Financial Incentives to Food and Retail Sectors and % of Traffic Shifted			
$5,000 (6.49%)	7,262	(16.20)	16.20
$10,000 (14.10%)	15,982	(76.07)	76.07
$15,000 (20.90%)	23,617	(172.91)	172.91
$20,000 (25.34%)	28,634	(284.13)	284.13
$25,000 (29.07%)	32,856	(413.72)	413.72
$50,000 (41.65%)	47,605	(1,244.39)	1,244.39
Targeted Programs Aimed at Large Traffic Generators			
Large buildings[d]	8,345	24.75	?
Large buildings and 250+ employees[d]	17,878	53.02	?
Unassisted deliveries		?	?

NOTE: Question marks indicate an absence of data for incentive costs and benefits. The percent values next to the incentive amounts represent the percent of the total truck traffic that is shifted to the off-hours.
[a]Estimated based on changes to congestion, operating costs, noise, and air pollution assuming 250 days/year.
[b]Estimated as the number of receivers that accept the incentive times the incentive amount.
[c]Assumed to be equal to the incentive cost.
[d]Assume 100% participation in OHD.

with respect to the increase in costs. It is optimal when the marginal benefits equal marginal costs, for a $\Delta B/\Delta C = 1$. The results indicate the following:

- In all cases, the economic benefits associated with increasing OHD exhibit diminishing returns although the incentive costs continue to grow.
- The optimal financial incentive is between $10,000 and $15,000 per year (14% to 21% of total truck traffic), depending on the composite VOT.
- Policies aimed at increasing OHDs at LTGs have great potential. By switching to the off-hours, the truck traffic generated by the 88 large buildings with their own ZIP code produces benefits comparable to the ones for the $5,000 incentive. Furthermore, if in addition, the truck traffic produced by the establishments with more than 250 employees is shifted to the off-hours, the economic benefits produced would be comparable to the ones for the $10,000 incentive. These benefits would be achieved at a fraction of the cost associated with providing financial incentives to the receivers.
- Unassisted OHDs represent a huge opportunity, although little is known about their market potential. However, a small survey of the receivers who participated in the pilot test indicated that 80% would accept unassisted OHDs if the liability issues are satisfactorily addressed. This could lead to a situation in which a small public investment could produce benefits similar to the ones brought about by the financial incentives.

Future research must tackle the design of policies, quantification of market potential, and implementation costs for both LTGs and unassisted OHD. Both concepts offer the potential to shift a significant number of truck-trips to the off-hours at a fraction of the cost. This must be a high-priority research area. It is important to mention that because the costs to receivers practicing unassisted OHD is much lower than for those with staffed OHD (shown in Figure 3), the final optimal amount of OHD would be much larger than the one in Figure 3.

CONCLUSIONS

The analyses conducted by the research team indicate that (*a*) financial incentives to receivers are very effective in inducing a shift of receivers and carriers to the off-hours; (*b*) the switch of truck traffic to the off-hours brings about substantial economic benefits; (*c*) on average, travel speeds from the depot to the first customer in Manhattan increase from 11.8 mph in the morning peak hours (6:00 to 9:00 a.m.) to 20.2 mph in the off-hours (7:00 p.m. to 6:00 a.m.); (*d*) on average, customer-to-customer travel speeds increase from below 3 mph during regular hours to about 8 mph during the off-hours; (*e*) there are substantial reductions in service times during the off-hours, from a maximum of 1.8 h/customer at 10:00 a.m. to a minimum of 0.5 h/customer during night hours; and (*f*) travel time

TABLE 4 Economic Analysis Results

	Cost to Receivers	Benefit to Carriers ($)	Benefit to Road Users ($)	Total Benefits ($)	Total Incentive Costs ($)	Net Benefits ($)	Marginal B/C ($\Delta B/\Delta C$)
Financial Incentive to Food and Retail Sectors							
$5,000 (6.49%)	(16.20)	28.72	57.10	85.81	(16.20)	69.62	5.30
$10,000 (14.10%)	(76.07)	63.20	84.42	147.62	(76.07)	71.55	1.03
$15,000 (20.90%)	(172.91)	93.39	100.24	193.63	(172.91)	20.72	0.48
$20,000 (25.34%)	(284.13)	113.23	146.15	259.38	(284.13)	(24.75)	0.59
Targeted Programs Aimed at Large Traffic Generators							
Large buildings	?	24.75	24.36	49.11	?	?	?
Large buildings and 250+ employees	?	53.02	53.60	106.62	?	?	?
Unassisted deliveries	?	?	?	?	?	?	?

NOTE: Question marks indicate an absence of data for incentive costs and benefits. B = benefits; C = costs.

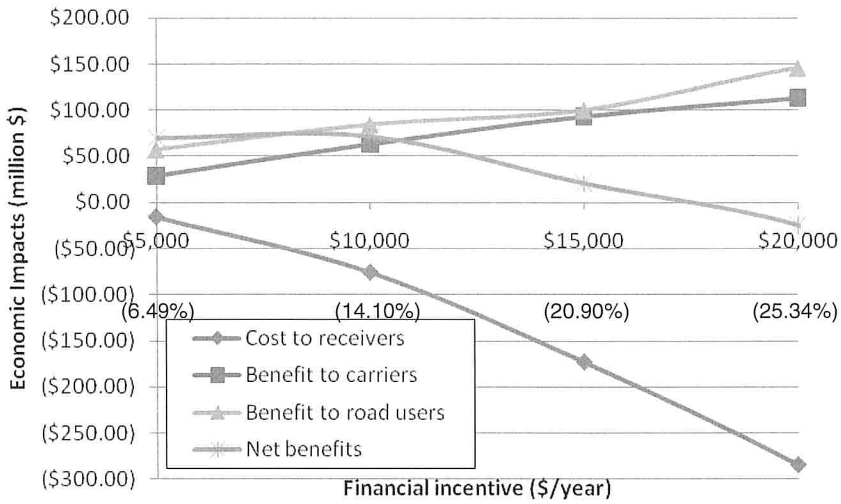

FIGURE 3 Cost and benefits of proposed OHD program (percents in horizontal axis indicate participation in OHD).

savings to regular hour traffic are substantial, amounting to 6% travel time reductions in Manhattan (4% if the increase in travel time during off-hours is considered). The analyses indicate that the economic benefits of a full implementation of an OHD program are in the range of $147 to $193 million per year. These benefits are the result of the productivity increases to the freight industry, travel time, and environmental pollution savings to road users. The analyses also conclude that the optimal incentive amount is a range between $10,000 and $15,000 per year, which corresponds to 14% to 21% of total truck traffic. The analyses also suggest that, should unassisted OHD be used, the optimal amount of OHD would be much larger.

However, in spite of the concept's great promise, there are a number of important questions that need to be answered before proceeding to a full implementation; most notably is the question of noise impacts on surrounding communities. Although no complaints were received during the execution of the small pilot test, it is natural to expect that community members would be concerned about noise impacts. In this context, it is important to both assess noise impacts and define appropriate mitigation procedures to ensure that local communities are not negatively impacted.

The research also identified new avenues with great potential: unassisted OHD and policies that target LTGs. The estimates indicate that about 4% to 8% of all deliveries are generated by LTGs. As a result, inducing LTGs to accept OHDs could have a noticeable impact on traffic congestion. It is equally important to note that because the number of LTGs is small (between 90 and 500, depending on the definition used), the coordination effort is insignificant when compared with the potential payoff. Unassisted OHDs provide a unique opportunity to achieve the benefits attributable to financial incentives, at a fraction of the cost. In this context, public-sector programs that successfully address the liability issues that deter businesses from doing unassisted OHD will increase off-hour activity. Over time, as the business sector gets accustomed to unassisted OHD, more establishments will join the practice. As an illustration of the potential of the concept, it should be noted that 90% of the receivers who tried unassisted OHD have continued the practice, even after the incentives ended, and 80% of the participating receivers indicated that they would use unassisted OHD if the liability issues were resolved.

In essence, the work done has clearly and unambiguously established that the proposed concept (*a*) is effective in inducing a shift of urban deliveries to the off-hours; (*b*) enjoys broad-based industry support; (*c*) would bring about substantial reductions in congestion and environmental pollution thus increasing quality of life; and (*d*) would increase the competitiveness of the urban economy. The fact that this is a win–win concept benefitting all participants in urban deliveries provides a unique opportunity for expansion and full implementation that should not be missed.

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Off-Hour Deliveries in Manhattan, New York City

Experiences of Pilot Test Participants

Matthew A. Brom, José Holguín-Veras, and Stacey Darville Hodge

This paper discusses the responses of participants in an off-hour delivery (OHD) pilot test to a postparticipation opinion survey. The pilot test was part of a project that investigated the use of financial incentives to receivers as a method to encourage OHD. The participants in the pilot test included eight carriers and 25 receivers; 12 used staffed OHD while the other 13 used unassisted OHD. In addition to the survey responses, information obtained from in-depth interviews with six of the participants provides insight into the operational benefits and potential difficulties of implementing OHD. Analysis of the responses indicates that carriers, receivers, and delivery drivers have a generally very favorable impression of their participation in OHD and shows that providing a financial incentive to receivers to encourage OHD is beneficial. Carriers saw reductions in costs, drivers experienced improved delivery conditions, and receivers saw substantial operational improvements such as being able to make better use of their staff as a result of the increased reliability of OHD. The potential of unassisted OHD is evidenced by the fact that most participants who used unassisted OHD during the pilot test continue to perform OHD without the financial incentive that was provided during the pilot test.

Congestion is experienced around the world in cities of various sizes. In smaller cities, the severe congestion is typically limited to a few locations during peak travel periods, but in larger cities, severe congestion can be widespread and occur during a large portion of the day, resulting in significant internal and external costs. The Texas Transportation Institute calculates that the cost of congestion in 2007 was $87.2 billion in the United States (*1*). This represents a 38% growth in congestion costs since 2000. This widespread congestion and its effects can easily be seen in New York City, where congestion is particularly problematic.

The New York City metropolitan region ranked second in the nation in terms of the cost of congestion, with $8.18 billion in 2007. This important region experienced a total of 379 million hours of delay (44 h per traveler) and consumed 239 million gallons of excess fuel (*1*). In light of the impossibility of solving the congestion problem by adding infrastructure, reducing urban congestion in such a complex metropolitan region requires the use of demand management techniques for both passenger and freight road users. One approach to managing freight demand is to encourage carriers to make off-hour deliveries (OHDs), which is what freight road pricing attempts to do. However, the experiences with freight road pricing indicate that it is not as effective as one would expect.

Holguín-Veras et al. (*2*) analyzed the impact on freight operations of a time-of-day pricing initiative implemented by the Port Authority of New York and New Jersey. It was found that about 70% of the carriers did not change their behavior in response to "customer requirements" and that only 9% of the carriers passed the increased costs to their customers. The key discovery was that carriers have a limited ability to unilaterally determine delivery times because it requires the consent of the receiver. Receivers prefer deliveries during regular hours when staff is on hand, as compared with OHD, where additional staff and costs related to security and operations may be required. Without a price signal that indicates the increased cost of delivering during regular hours reaching the receiver, the receiver has no incentive to switch. Hence, imposing road pricing on truck traffic during regular hours (6:00 a.m. to 7:00 p.m.) has limited potential for shifting a substantial number of trips to the off-hours (7:00 p.m. to 6:00 a.m.). The end result is that carriers are penalized for delivering during the regular hours without being able to change behavior because the receivers do not give their consent. A better approach is to reward receivers for receiving OHDs. Because receivers are the customers, their willingness to accept OHDs will pull the carriers (who are willing to deliver during off-hours) into making OHDs, as the receiver is the customer, and thus achieve the goal of shifting deliveries to the off-hours.

The authors have conducted research on one such alternative approach to reducing congestion. The approach provides a financial incentive to receivers (the key decision makers) in exchange for accepting deliveries during the off-hours. The research was part of a project funded by the U.S. Department of Transportation. As part of this project, a pilot test of the concept was conducted in Manhattan. Details on the project and the resulting impacts can be found in multiple documents by Holguín-Veras et al. (*3, 4*).

While the quantification of the effects on travel conditions and the economic impacts of the proposed approach are very important in any project dealing with transportation issues, feedback from those directly affected by the policy is also very important. Feedback from

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the pilot test participants assists in verifying initial hypotheses and provides insight into what improvements should be made in the future.

This paper focuses on the analysis of the feedback solicited from the participants of the pilot test regarding their impressions of the pilot test and OHD. The paper provides an overview of the structure of the pilot test, the structure of the opinion surveys given to the participants, the results of the analysis of their responses, and feedback obtained through in-depth interviews conducted with various participants. A companion paper (*3*) discusses the overall impacts of an eventual full implementation of an OHD program as well as the results of the pilot test. A conclusion section summarizes the key findings.

SMALL-SCALE DEPLOYMENT

The focus of the pilot test was on the food and retail industries. The research team selected these industry segments because they generate a significant number of daily deliveries in Manhattan and were found to be more inclined to receive OHD when presented with a financial incentive (*4, 5*). The pilot test was organized into three groups, which were based on four companies identified as "industrial partners." These companies are industry leaders within their respective fields and include Sysco, Foot Locker, Whole Foods Market, and New Deal Logistics. The pilot test consisted of the industrial partners and a set of their respective carriers–vendors or receivers–customers. The three groups thus represent three different scenarios: an independent carrier servicing a retail chain, a vendor servicing multiple receivers, and a receiver being serviced by multiple vendors. In total, eight carriers–vendors and 25 receivers fully participated in the pilot test. Each of the groups was allowed to begin the pilot test as soon as the logistical arrangements were in place for that particular group. The three groups completed their 1-month participation in the pilot test during the period of October 2009 to January 2010. To protect the identities of pilot test participants, the results in the remainder of the paper will be presented by groups of carriers and receivers and denoted as Group 1, Group 2, and Group 3. In referencing a particular receiver or carrier, the participant will be designated as Receiver 1, Carrier 1, and the like.

The participants were given a financial incentive to participate in the pilot test. The receivers were provided $2,000 for successful completion of the 1-month pilot test, a higher value than the $10,000 per year incentive considered during the project research for long-term participation in OHD. This higher incentive was used to compensate the businesses for the setup costs incurred as a result of switching their receiving operations at the beginning and end of the pilot test. The carriers were provided an incentive of $300 to compensate for these setup costs. The carrier incentive was smaller than that of receivers because carriers tend to benefit in general from OHD. The carriers designated as industrial partners were given a payment of $3,000 because they invested a significant amount of time, effort, and expense in the organization and implementation of the pilot test, including many conference calls involving high-level executives. The amount of resources invested by the industrial partners demonstrates the level of industry support that the concept enjoys.

Upon completion of the pilot test, participating businesses were asked to complete a survey regarding their experiences with performing OHD. Surveys were given to the receivers, carriers, and route drivers. Additionally, in-depth phone interviews were conducted with some of the participants.

RESULTS FROM OPINION SURVEYS

The research team found it vital to get input from the participants regarding their participation in the pilot test to verify initial hypotheses regarding OHD as well as identifying problems and benefits. Four versions of the opinion survey were used: carrier management, receiver management, drivers, and Group 1 receiver management. The surveys can be found in the project draft final report (*4*). The carrier and receiver management surveys asked for the number of employees working per day and the number of employees dedicated to back-room operations as well as questions regarding their impression of OHD, the effect OHD had on their operations, the likelihood of requesting OHD in the future, and their interest in unassisted OHD if liability issues were addressed. Open-ended questions were asked about how OHD specifically affected their operations and about their likes and dislikes of OHD. The driver survey asked questions about the driving conditions experienced during the off-hours. Drivers were also asked to provide their particular likes and dislikes regarding OHD and to indicate their delivery time preference. The Group 1 receiver management survey is the initial version of the receiver management survey. The original survey did not specify that the manager should "assume that the additional costs corresponding to the staff working in the off-hours have been taken care of by means of a financial incentive" when responding. This omission on the Group 1 survey was problematic because the participation of the receivers was coordinated through the regional headquarters. Consequently, the store managers were not aware of the financial incentive being provided for their participation. This needs to be kept in mind when analyzing the Group 1 receiver feedback. Upon receipt of the Group 1 receiver responses indicating concerns about additional costs, the team decided that clarification was required regarding the presence of the financial incentive. The revised receiver management survey was then created, including the previously mentioned statement in addition to a question about interest in unassisted OHD. The following three sub-sections provide information on the operational changes resulting from participation in the pilot test, the participants' impressions of OHD, their experience during the pilot test, and the results of the survey given to the participating delivery drivers.

Changes in Operations of Participants During Pilot Test

As expected, most businesses encountered a change in operations during the pilot test. To put the changes in context, it should be noted that the Group 1 deliveries were shifted to the late evening hours (7:00 to 9:00 p.m.), while Group 2 and Group 3 deliveries where shifted to the overnight hours (midnight to 6:00 a.m.). The resulting changes in operations were both positive and negative. Table 1 shows the level of operational change experienced by the participants and that the effect on their operations was minimal to moderate. To assist the reader in understanding the range of responses, the unedited participant responses are provided following Table 1. The responses in Table 1 indicate only the magnitude of the change and not whether the change was positive or negative.

TABLE 1 Effect of Off-Hour Deliveries on Operations: How Much Did Off-Hour Deliveries Affect Your Operations?

Survey Question and Respondent	Amount of Change in Operations					
	None (1)	Minimal (2)	Moderate (3)	Significant (4)	Drastic (5)	Mean
Group 1 receivers	1	2	3	2	0	2.75
Group 2 receivers	0	1	3	5	1	3.60
Group 3 receivers	0	4	0	0	0	2.00
All carriers	1	4	2	1	0	2.38
Total	2	11	8	8	1	

To the survey question, "How were your operations affected?" Group 1 receivers responded:

- "The store's shipment arrived during store closing. The shipment remained on floor until the next morning, causing the store to be cluttered at start of next business day."
- "Reschedule of associates to come in for shipment delivery. If the delivery truck was running late, the store incurred overtime. Store had to add an extra associate to process shipment at late delivery time."
- "Store had to adjust work schedule to receive product."
- "Change of associate's schedules—store had to work receiver all day to accommodate both parcel and pool deliveries. Due to the hours accumulated that day, the associate was scheduled an extra day off during the week. All other associates then also had to be rescheduled to accommodate the day off of the receiving associate."
- "Receiving off-hours slowed processing and start for the next business day. Shipment boxes were in the way of store opening."
- "Not as many associates were available to work at the start of business day. It was difficult to schedule associates to receive shipments."
- "Pool agent arriving after store closure. Store paid overtime to keep personnel late."

Group 2 receivers responded:

- "Changes in operations dealing with delivery."
- "Very helpful to have order in prior to start of business. As luck would have it, we would often get delivery in during a rush period. Having it put away before opening was great. Also can change the way I order/stock inventory."
- "Required additional employee scheduling and costs, required additional time for returns/exchanges of items."
- "They were always on time and we save by not having to put everything in the walk-in ourselves."
- "Never missing products."
- "Makes delivery more easy."
- "More reliable."
- "We prep a lot of food for stores, and delays in delivery time will cost us real labor dollars."
- "Better delivery times."
- "It was much better than having to interrupt our customer space with boxes and mess."
- "Rescheduling of labor."

Group 3 receivers responded:

- "Most of our deliveries were already overnight."
- "Scheduling."
- "Scheduling of deliveries, more timely deliveries due to less traffic at night."

Respondents in the all carriers category noted:

- "We operate 24/7; the off-hour pilot required interim rescheduling of one driver's hours and establishing new dock routine."
- "We increased our night routes from one to four."
- "Open a little earlier."
- "More time to make sales calls, follow up with clients."

Most of the changes incurred by Group 1 receivers involved scheduling and overtime costs. Once again, the responses regarding overtime must be viewed in light of the fact that the managers were not aware of the financial incentive being paid (with the intended purpose of covering such additional costs). The issue of scheduling is to be expected for a month-long pilot test in which operations are switched to the off-hours in order to participate and then back to the regular hours upon completion. Regarding scheduling issues in general, it was mentioned by one of the carriers that receivers who have a significant number of part-time employees often run into the problem of trying to schedule employees around their nonwork commitments, which are likely more numerous in the off-hours. Taking these things into consideration, the project team thinks that it is reasonable to assume that the changing of schedules would not be as significant an issue in a full implementation of OHD because the changed schedule would become the new schedule with limited further changes required.

The changes in operations of the Group 2 receivers were positive overall. Many of the participants in this group chose to use unassisted OHD in which a Group 2 carrier's driver was provided access to their facility. The driver could thus arrive and place the ordered items in the walk-in refrigerator without the assistance of the receiver's employees. This arrangement was found to be beneficial because it provided greater reliability of the delivery time without the need to reschedule labor and without increased costs. The significant benefits provided by using unassisted OHD is evidenced by the majority of the participating Group 2 receivers continuing to receive OHD, even without the financial incentive.

The changes incurred by the Group 3 receivers tended to be minimal, because many already used OHD for their largest deliveries.

Consequently, the changes incurred tended to be neutral or positive. They were included in the pilot test because few of their smaller vendors performed OHD.

The management of the carriers indicated that the operational changes required for OHD were minimal. This was expected by the project team because of conversations with the participating carriers during the organization of the pilot test. A majority of carriers indicated that the main obstacle to OHD was that the receiver was not open to receive the delivery.

Overall Impressions of OHD

The surveys asked participants about their overall impression of OHD as well as their likelihood to participate in OHD in the future. The Group 2 and Group 3 receivers were also asked about their interest in unassisted OHD. The response scale of the results ranged from 1 to 5, with 1 indicating a very favorable response, and 5 indicating a very unfavorable response. The results are shown in Table 2.

Receiver Opinion Survey Responses

The participating receivers were asked about their particular OHD likes and dislikes. Management was asked about their likelihood to request OHD in the future and whether they would consider implementing unassisted deliveries if liability concerns were addressed. The following sections summarize their responses.

Group 1 Receivers (Not Aware of the Financial Incentive Being Provided)

The Group 1 receiver responses were most likely impacted by individual establishments not having been informed by regional head-

TABLE 2 Summary of Survey Responses from Receivers, Carriers, and Drivers

Survey Question and Respondent	Number for Each Type of Response					Mean
	Very Favorable (1)	Favorable (2)	Neutral (3)	Unfavorable (4)	Very Unfavorable (5)	
Group 1 Receivers (not aware of the financial incentive being provided)						
What was your impression of off-hour deliveries?	0	1	1	4	2	3.88
If it were up to you, how likely are you in the future to request deliveries from your vendors in the off-hours?	0	1	3	2	2	3.63
Group 2 Receivers						
What was your impression of off-hour deliveries?	6	6	0	0	0	1.50
If it were up to you, how likely are you in the future to request deliveries from your vendors in the off-hours?	9	1	2	0	0	1.42
If all liability issues were addressed, would you be interested in receiving unassisted deliveries?	2	3	0	0	1	2.17
Group 3 Receivers						
What was your impression of off-hour deliveries?	0	2	2	0	0	2.50
If it were up to you, how likely are you in the future to request deliveries from your vendors in the off-hours?	1	2	1	0	0	2.00
If all liability issues were addressed, would you be interested in receiving unassisted deliveries?	0	1	0	3	0	3.50
Carrier Management						
What was your impression of off-hour deliveries?	2	4	1	1	0	2.13
If it were up to you, how likely are you to make deliveries during the off-hours if requested from your customers?	3	4	0	1	0	1.88
How did making off-hour deliveries affect your costs?[a]	0	3	3	2	0	2.88
Delivery Drivers						
Preference for off-hour deliveries[b]	10	1	0	0	1	1.42
Availability of parking	10	2	0	0	0	1.17
Level of congestion	10	2	0	0	0	1.17
Level of stress from driving	10	2	0	0	0	1.17
Average travel speed	6	6	0	0	0	1.50
Amount of time needed to complete the delivery route	6	5	1	0	0	1.58
Length of time needed at each stop to deliver goods	5	5	2	0	0	1.75
How safe do you feel making off-hour deliveries	3	3	5	0	1	2.42

[a]Scale of responses was 1 = moderate decrease to 5 = moderate increase.
[b]Scale of responses was 1 = strongly prefer off-hours to 5 = strongly prefer regular hours.

quarters about the financial incentive to cover additional costs resulting from OHD. The Group 1 surveys also did not explicitly state that the managers should assume that any additional costs incurred as a result of staffing during the off-hours would be covered by the financial incentive. This may be reflected in the receivers' overall unfavorable view of OHD (3.88) and that they were unlikely to request OHD in the future (3.63.) In essence, the responses reflect the opinion of participants that have been forced to do OHD without receiving a financial incentive (in comparison with participants that voluntarily participate in OHD because of the incentive provided). The responses to questions about their likes and dislikes of OHD varied. Four of the eight receivers indicated that there was nothing they liked about OHD. Of the other four receivers, three said the delivery process did not interfere with dealing with customers, and the fourth indicated the delivery process was quicker. Many of the receivers chose staffing issues and overtime costs as things they disliked. Multiple receivers indicated that they did not like getting the deliveries near closing time; comments were included about the potential of missed sales caused by not being able to stock the product until the next day. It should be noted that the majority of the dislikes are related to the issues of additional costs and scheduling, both of which were discussed in the previous section on operational changes.

To the survey question, "What did you like about receiving deliveries in the off-hours?" respondents made the following comments:

- "Store could process freight faster in off-hours."
- "Nothing."
- "Receiving shipment did not compete with customers. Boxes from shipment were not on the sales floor. Store was clean for early morning shoppers."
- "Nothing."
- "Less traffic in store—very few customers were interrupted due to the receiving of shipment."
- "Receiving shipment did not compete with business. Customers were not interrupted by receiving shipment."
- "Nothing."
- "Store manager did not like off-hours deliveries."

The survey question, "What did you dislike about receiving deliveries in the off-hours?" drew the following responses:

- "Nothing."
- "Store could not get new product out on sales floor until the next business day, causing a loss of sales."
- "Late hours—clean up of store in evening plus late receiving of freight necessitated store personnel to work late adding extra overtime."
- "Store parcel freight is delivered early in the morning. Manager had to schedule stock person late in the evening to get pool freight received. If the pool agent was late, store personnel also had to stay late, resulting in payment of overtime to associate to receive shipment."
- "Changing of schedules for all personnel to accommodate late pool deliveries."
- "Do not like receiving shipment so close to store closing time."
- "Missed sales opportunities—large shipments could not be processed until the next morning. Parcel shipments also received in the morning got mixed with pool shipments."
- "Manager had to stay late after regular store hours to receive freight. Store had to pay overtime to associates to receive shipment."

Group 2 Receivers

Group 2 receivers had a very favorable impression of OHD (mean, 1.50), with a high likelihood of requesting OHD in the future (mean, 1.42). These establishments also indicated a favorable view of the use of unassisted OHD (mean, 2.17). The view of unassisted OHD is in actuality more likely "very favorable," considering that the six establishments not responding to the question are all currently using unassisted OHD. It should be noted that the majority of the Group 2 receivers used some form of unassisted OHD in which a carrier delivered the product to their establishment before they opened and placed the order in the walk-in refrigerator–freezer. Overwhelmingly, the participants indicated that they liked the increased reliability of OHD and liked having the product earlier in the day, thus not interfering with customers or the morning staff routine. These results are supported by the fact that many of them, including all participants who used unassisted OHD, are still receiving OHD without the incentive provided by the pilot test. Of those using unassisted OHD, the dislikes included not being able to verify the order at time of delivery, thus making the process of remedying order errors more difficult. Of those not using unassisted OHD, the main complaint is the additional staffing costs.

The following responses were given to the survey question, "What did you like about receiving deliveries in the off-hours?"

- "Receiving deliveries in the off-hours will not interrupt the operation during the busy hours."
- "Very helpful to have order in prior to start of business. As luck would have it we would often get delivery in during a rush period. Having it put away before opening was great. Also can change the way I order/stock inventory."
- "Receiving deliveries during the off-hours is more convenient, and plus I receive my order earlier in the day."
- "There was no/little disruption of customers overlook experience due to deliveries, quick check in and rotation into stock, did not affect the kitchen cooking process."
- "They were never late for delivery!"
- "No issues with delivery."
- "Reliability!"
- "Reliability, and they put stuff away."
- "Labor savings."
- "Better delivery times."
- "It was much better than having to interrupt our customer space with boxes and mess."
- "The advance receipt of goods."

The survey question, "What did you dislike about receiving deliveries in the off-hours?" elicited the following comments:

- "The additional cost of assigning a staff to receive the orders in the off-hours."
- "We arranged to provide access to the driver . . . so that product could be kept safely before staff gets in. While we didn't have a problem . . . on a larger scale of this could lead to issues that we would deal with."
- "Nothing."
- "No real issues."
- "All Good."
- "Nothing."
- "No dislikes."

- "Additional cost for employee dedicated to handle delivery, return/exchange process is made more difficult."
- "If you are shorted or get wrong item, you cannot give [it] to the driver the next day. Sales guy has to come and get it."
- "No immediate verification."
- "It is problematic to return items."
- "Can't check quality or wrong items."

Five of the 12 comments listed above are related to the issue of potential order errors and the return process. This will be discussed later in the paper.

Group 3 Receivers

The results from the Group 3 receivers indicate a favorable impression of OHD (mean, 2.50) and a likelihood of requesting OHD in the future (mean, 2.00). This is expected because the Group 3 receivers already use OHD for their largest deliveries. This also explains the disinterest in requesting unassisted OHD (mean, 3.50), because staff is already on hand. Considering that the Group 3 receivers already use OHD where and when possible, the pilot test was not anticipated to result in a large shift in their operations and opinions regarding OHD. All of the Group 3 receivers indicated that they like the reduced amount of congestion during the off-hours when receiving deliveries. The only dislike was that one store indicated that the pilot test resulted in more overnight work.

To the survey question: "What did you like about receiving deliveries in the off-hours?" Group 3 receivers indicated the following:

- "Less traffic on the street."
- "Avoiding traffic from rest of building."
- "Less congestion outside receiving. Less late deliveries."
- "Less traffic congestion and pedestrians."

The survey question, "What did you dislike about receiving deliveries in the off-hours?" drew the response, "Requires more overnight."

Carrier and Driver Opinion Survey Responses

Two surveys were given to the participating carriers. The first was given to the carrier's management and dealt with the effects of OHD on their operations as well as their likes and dislikes of OHD. The second was given to the carrier's drivers who participated in the pilot test and was concerned with the driver's observations of travel conditions as well as their individual likes and dislikes of OHD. The following sections summarize their responses.

Carrier Management

The managers of the participating carriers had a favorable impression of OHD (mean, 2.13) and a high likelihood of making OHD if requested by the receivers (mean, 1.88). The overall effect of participating on the carriers' costs was found to be a "slight decrease" to "neutral" (mean, 2.88). The improvement in delivery operations (i.e., reduced congestion and increased parking availability) was the main item they liked about OHD. Improved timing was also mentioned, as was the potential of being able to make better use of their equipment. On the other hand, security issues about the safety of their drivers (which will be discussed later in the paper), an earlier start of the workday, and having to wait for receivers (which could be remedied by the implementation of unassisted OHD) were mentioned as things the managers disliked about OHD.

Carrier managers answered the survey question, "What did you like about making deliveries in the off-hours?" as follows:

- "Reduced parking violations, available parking for our vehicles, fewer traffic delays."
- "Increased the revenue potential of hard assets—the truck. Decreased the delays and cost of traffic congestion. Allowed the potential for increased revenue and decreased cost by expanding the hours each day for producing revenue."
- "Helped with time spent at loading docks. Less wait time."
- "Timing."
- "Less stressful, more room to park."
- "Less congestion and much quicker deliveries."
- "We don't like it."

Managers responded to the survey question, "What did you dislike about making deliveries in the off-hours?":

- "Safety of our delivery associates at night."
- "Nothing I cannot take care of. Security in the hours 3:00 a.m. to 6:00 a.m. may require some change. Nothing unexpected."
- "Waiting for customers to open."
- "Nothing."
- "Longer days, but more productive."
- "Getting up earlier."
- "We need to wait for their receiving for about 2 hours."

Drivers

The drivers who made OHDs during the pilot test for the participating vendors–carriers were asked to complete a survey about the changes they experienced driving during the off-hours as compared with the regular hours. The results are shown in Table 2. The drivers indicated an increase in available parking (mean, 1.17), a result of fewer vehicles competing for a limited number of spaces. This increase in parking availability allows drivers to park closer to the receiving establishment, thus reducing the amount of time needed at each stop to deliver goods (mean, 1.75). This is consistent with Holguín-Veras et al. (*3, 4*), who found a reduction in service times from an average value of 1.8 h per stop at 10:00 a.m. to 0.5 h per stop at 10:00 p.m. This reduction in time needed at each stop, combined with the increase in average travel speed (mean, 1.50), resulted in a decrease in the amount of time needed to complete the route (mean, 1.58). Much of these improvements can be attributed to the decreased level of congestion (mean, 1.17), which helps to reduce the level of stress from driving (mean, 1.17). The drivers also indicated a slight increase in their feeling of safety (mean, 2.42), which contrasts with carrier management's indication that the safely of their drivers was their top concern regarding OHD. Overall, the drivers strongly preferred OHD (mean, 1.42), with 10 of the 12 drivers indicating that they

"strongly prefer off-hours." A compilation of the stated likes and dislikes of the drivers is provided below.

The survey question, "What did you like about making deliveries in the off-hours?" was answered as follows:

- "Easier to maneuver through the city, easier to park, and less foot traffic to hold me up."
- "Not having to deal with customer."
- "My stores were in midtown. 7:00 p.m. to 9:00 p.m. window has less traffic."
- "No stress."
- "The reasons addressed in the seven questions above."
- "No tickets."
- "Streets are easier to manage and better parking."
- "Less congestion and much quicker deliveries."
- "I don't like it."
- "Less traffic, less stress."
- "My stores were in midtown. 7:00 p.m. to 9:00 p.m. window has less traffic."

Drivers answered the survey question, "What did you dislike about making deliveries in the off-hours?" with the following statements:

- "I have no dislikes, as long as I have a job to do."
- "Nothing."
- "Nothing."
- "None."
- "Waiting for customers to open."
- "Longer day, but less stressful."
- "Getting up earlier."
- "I need to wake up very early and I need to wait for the store's receiving for a long time."
- "Nothing I could think of."
- "7:00 p.m. to 9:00 p.m. my stores in midtown still had theatre district traffic."

RESULTS FROM IN-DEPTH INTERVIEWS

In-depth telephone interviews were held with executives from six of the participating businesses. These interviews were conducted after the pilot test was completed and all satisfaction survey results were received and analyzed. Of the six interviews, two were with carriers and four were with receivers. Unfortunately, because the Group 1 receiver's participation was coordinated through the regional headquarters, the project team was at no point in direct contact with the Group 1 managers and could not interview them. The following paragraphs summarize the feedback provided during these interviews.

An executive with Carrier 1 was interviewed March 15, 2010. The executive was very pleased with the results of the pilot test. Benefits experienced included significant increases in travel speeds, the availability of parking, and reductions in service times. For this carrier, the receiver had a limited time window for OHDs to occur. This resulted in Carrier 1 being able to make OHDs to a maximum of only three receivers per route. The executive indicated that their receivers hire a lot of part-time employees, and rescheduling around their nonwork schedules makes the staffing issue more problematic. The executive indicated that the cost savings on the participating routes was in the area of 20% during the pilot test. With a wider implementation, the executive said that Carrier 1 could make better use of the trucks by being able to send them out on two routes daily (one in the regular hours and one in the off-hours). One idea that was mentioned, which is worth further consideration, is the concept of dropping goods at secure locations during the off-hours and then sending employees during the regular hours to use electric and/or small vehicles to deliver these goods.

On March, 17, 2010, executives from Carrier 2 (C2) discussed their experiences with the pilot test and OHD in general. Before the pilot test, C2 had tried to encourage OHD among its receivers, with the result of being able to implement a single off-hour route. One executive indicated that their troubles in getting receivers to shift to the off-hours mainly resulted from the difficulty in coordinating the receiver's staffing needs, obtaining access or permission from landlords to deliver to the buildings, and coordinating with the unions about security personnel and freight elevator operators. C2 currently has approximately 30 trucks loaded and prepared to leave by midnight and thus has a large capacity to increase OHD. With the implementation of the financial incentive during the pilot test, the number of off-hour routes increased from one to five.

The majority of C2's receivers participating in the pilot test used unassisted OHD by providing C2 a key to their establishment, which allowed them to access the facility and place the delivery in the walk-in refrigerator. This is an approach that C2 has tried to encourage, without much success, in the past by offering to install key boxes at customer locations, thus allowing access to the facility. Upon completion of the pilot test, many of C2's receivers chose to continue to receive OHD. Consequently, C2 was able to keep three of the four new off-hour routes created for the pilot test. C2 experienced a reduction in parking tickets and costs associated with fuel and overtime. The reduction in parking tickets was one of the major incentives for C2 to participate. Each time one of C2's trucks gets a ticket it actually gets multiple tickets. This means that some infractions are not primary infractions, where the truck cannot be stopped for that infraction alone but can be ticketed if they are stopped or ticketed for a separate primary offense. C2 pays more than $1 million a year in parking fines, for an average of $500 per truck per month, which is consistent with results from the previously mentioned New York State Department of Transportation study conducted by Holguín-Veras (*6*). In addition to the cost benefits mentioned were the reduced wear and tear on the vehicles, less conflict with others about shared use of building elevators, fewer errors in deliveries (only two errors in roughly 750 OHD during the pilot test) because the trucks were loaded before stock levels began to dwindle, the ability to reuse the trucks later in the day, and lower levels of frustration for the drivers. No complaints were received during the pilot test from the OHD routes. These drivers, although they were not paid premium wages, saw an increase in their hourly wages because the driver gets paid per route. Consequently, the more rapidly a route is completed, the higher the effective hourly wage. The main concerns C2 had about OHD were the safety of the drivers and the public reaction to the effects created by a large-scale implementation (e.g., noise, increased night traffic).

According to a March 19, 2010, interview with executives from Receiver 1, participation was relatively seamless because it was receiving OHD prior to the pilot test (it was mentioned that some of the suburban receivers use unassisted OHD with the assistance of double doors). Participation involved finding space for the deliveries

within the established routine. Because of a lack of storage, which is considered typical in Manhattan, the deliveries go straight from the truck to the shelf. With a few exceptions, the stocking of the shelves is done by Receiver 1 employees, and thus the additional deliveries increased the overnight workload. The executives also provided their insight into obstacles for businesses regarding OHD.

Vendors mentioned that Receiver 1 is typically only one of many receivers on a route and that without the other receivers participating in OHD, it would be problematic for many vendors to participate. Additionally, many vendors prepare their goods in the morning and, to deliver the goods earlier, the preparation would have to start earlier. Customers who do overnight stocking and cleaning may not have the manpower to also receive deliveries. In these cases, the issue of supervision and security arises. While Receiver 1 is in the food industry, the executives mentioned that retail may be a good target for unassisted OHD because the issue of product spoilage would not apply. They did express a concern over "push back" from residents in surrounding areas in a full implementation of OHD.

The executive from Receiver 2 was interviewed March 24, 2010. The executive indicated that they were incredibly pleased with their OHD experience. Breakfast is their busiest time, and they previously received deliveries between 7:00 and 10:00 a.m., which was problematic. In the past, it was difficult to handle the receiving because of the uncertainty of when the truck would actually arrive. With unassisted OHD, the executive knew the goods would be waiting for staff when they arrived in the morning. Receiver 2 is located in a building with 24-h access, so they provided a refrigerator key to the vendor, who would enter the building and put the order away. It was also mentioned that during the off-hours the building management would allow deliveries via the front door of the building because of the lack of building traffic, rather than requiring the use of the freight entrance. The executive indicated that they initially had concerns about how order errors would be handled, but during the pilot test Receiver 2 experienced only two order errors (out of an estimated total of 750), and in both cases the errors were noted by the delivery driver, who resolved the problem.

The March 26, 2010, interview was with an executive from Receiver 3, who was very pleased with the OHD project. Receiver 3 used unassisted OHD previously and continues to do so. Previously, products were ordered for receipt in the next 1½ days because of the uncertainty about exact delivery time. Since the implementation of OHD, the management has been able to order more efficiently. While the executive indicated that initially there was concern over not being able to check orders as they arrived, it was noticed that errors were discovered more quickly when the manager could check the order upon arrival in the morning versus being rushed during business hours. In the beginning, there were some problems with resolving order errors, but the process was worked out with the vendor by the end of the pilot test. The executive indicated that they thought there was a lack of trust among restaurant owners, which would be an impediment to a larger implementation of OHD. He also indicated that they were comfortable providing their participating vendor with a key to their establishment, partly because of their security measures but primarily because of the size and reputation of the company. It was also mentioned that the vendor's drivers were union drivers, and that the receiver thought it unlikely that a driver would risk losing a good job over a ". . . 75 cent bag of chips." However, they would not feel as comfortable doing the same with their smaller vendors. The executive also indicated that they had changed primary vendors since the pilot test and thought that receiving deliveries during the off-hours gave them some leverage with their new vendor because the vendors save money by making OHD. The new vendor did not specifically give them a set discount, but the executive thinks they are receiving a slight discount in addition to being able to avoid some fuel surcharges.

An executive with Receiver 4 was interviewed April 27, 2010. Receiver 4 is located in a building with 24-h security. The executive indicated that management was very pleased with OHD because it meant staff would not be taken away from the task they were performing to receive a delivery, it kept the product from sitting around, and it kept the unprepared food from the view of the customer. The executive said deliveries could be made more quickly during OHD because the drivers were allowed through the front of the building by building management rather than having to use the freight entrance. Additionally, checking the already delivered orders for errors was found to be more efficient because the store manager had more time to review the received order and the vendor had more time to correct any mistake. When orders arrived during business hours, errors went overlooked because of the rushed nature of the inspection. In addition to the deliveries received as part of the pilot test, some of the other smaller vendors (e.g., bread, bagels) deliver during the off-hours and leave the product with the building security. The executive indicated that they are no longer able to receive OHD from the participating vendor because of issues with their facility layout but would like to be able to do so again in the future, even without the financial incentive.

CONCLUSIONS

A successful pilot test was conducted as part of a U.S. Department of Transportation–funded project that investigated the use of financial incentives to receivers to encourage OHD. This paper shows that the participants of the pilot test had an overall favorable impression of OHD. The management of the receivers participating in the pilot test indicated a favorable impression of OHD. The exceptions are Group 1 receivers, who were not aware of the $2,000 per store financial incentive that was being provided in exchange for their participation. This is seen by the complaints made by store management about the additional costs.

Many of the participating receivers used unassisted OHD. Unlike staffed deliveries, where the receiver has an employee present to receive the delivery, unassisted OHDs do not require the presence of receiver staff. In the pilot test, these unassisted OHDs took the form of the receiver providing the carrier with access to the facility for deliveries during the off-hours. Overwhelmingly, the receivers liked having the deliveries waiting for them when they arrived in the morning, as compared with having to wait for the deliveries during business hours, where the work process would be interrupted. Initial concerns over the remedying of order errors were not found to be an issue.

Carrier management found that during the off-hours they experienced cost savings as a result of faster travel speeds, fewer parking tickets, and less fuel consumption. The Group 2 carriers were able to increase the number of off-hour routes from one to five during the pilot test, and still continue to maintain four off-hour routes because a majority of their receivers who participated in the pilot test have continued using OHD after the pilot test. The drivers indicated much better driving conditions in the off-hours (e.g., more parking, less congestion) and lower levels of stress. The surveyed drivers indi-

cated that they "strongly prefer off-hour deliveries." The one area where carrier management and drivers differed in opinion was in regard to safety. While management indicated that safety was their top concern, the drivers expressed an increased sense of safety making OHDs.

The pilot test indicated that OHDs are not only beneficial to carriers and drivers but that receivers see operational benefits significant enough that they continue to receive OHD without a financial incentive. In summary, this paper shows that providing a financial incentive to receivers is an effective method of encouraging OHD, which has significant financial and operational benefits to both carriers and receivers.

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Estimating the Benefits of Considering Travel Time Variability in Urban Distribution

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Urban distribution systems typically require carriers to deliver goods to receivers within specified time windows. This paper presents procedures that allow the variable nature of travel times to be incorporated within optimization methods for the vehicle routing problem with time windows. Expressions are presented for determining the penalty costs associated with truck arrivals at customer locations with time windows when the travel times between customers are normally distributed. Formulations of this problem using stochastic programming and robust optimization (RO) are presented. Stochastic programming procedures require numerical integration techniques to be used and thus are computationally demanding. However, RO allows solutions to be generated with only a limited number of travel time scenarios between customers and, thus provides a practical means of incorporating travel time variability. A procedure was developed for estimating the cost savings of implementing the RO solution. The benefits of explicitly considering the variability of travel times between customers were estimated using a case study based on a distribution problem in Melbourne, Australia.

Contemporary urban distribution systems frequently involve carriers having to deliver goods within narrow time windows specified by customers. Information relating to the variable nature of travel times between customers has the potential to reduce transport costs for carriers and provide higher levels of service for receivers of goods. This paper presents practical procedures that allow the uncertainty of travel time between customers to be incorporated with the vehicle routing problem with time windows. Historical travel time patterns can be represented by probability distributions. The benefits of incorporating the uncertainty of travel times between customers is illustrated using a small problem based on the distribution of medical products in Melbourne, Australia.

Urban delivery systems are characterized by multistop vehicle tours (*1*). Traffic congestion can cause substantial increases in carriers' operating costs and cost structures (*2, 3*), as well as increased production costs in urban areas (*4*). Recent advances in Global Positioning System technology allow detailed information relating to the variability of travel times for freight vehicles delivering goods in urban areas (*5*).

Stochastic vehicle routing problems occur whenever some elements of the problem are considered to be random, such as demands, customers, or travel times (*6*). Previous work on stochastic routing with variable travel times has largely focused on the stochastic traveling salesman problem and addresses the problem of determining a tour that maximizes the probability of completion by a specified time where the travel times between cities are independent, normally distributed random variables (*7–9*).

The savings algorithm (*10*) was applied to determine the optimal routes with random travel times between bank branches (*11*). Laporte et al. (*12*) presented three mathematical programming models for the vehicle routing problem with stochastic travel times where a penalty proportional to the duration of vehicle routes in excess of a preset constant was incurred. Kenyon and Morton (*13*) considered the stochastic vehicle routing problem with random travel and service times. Two alternative objective functions were formulated on the basis of the length of the longest route, the expected completion time, and the probability of completing a project by a prespecified deadline.

There has been limited investigation into vehicle routing that considers the stochastic nature of travel times in traffic networks (*14*). Procedures previously developed for solving the vehicle problem with time windows and stochastic travel times have been found to be computationally expensive (*15–17*). A robust optimization model of the vehicle routing problem with soft time windows is presented in this paper as a practical and efficient means of incorporating the variation in travel times in urban distribution networks to improve the operating costs for carriers as well as service levels for customers.

The vehicle routing problem with time windows can be defined as follows. Let $\boldsymbol{G} = (\boldsymbol{U}_0, \boldsymbol{E})$ be a graph where $\boldsymbol{U}_0 = \{\boldsymbol{u}_0, \boldsymbol{u}_1, \ldots, \boldsymbol{u}_{N+1}\}$ is the vertex set, $\boldsymbol{U} = \boldsymbol{U}_0 \setminus \{\boldsymbol{u}_0\}$, and $\boldsymbol{E} = \{(\boldsymbol{u}_i, \boldsymbol{u}_j): \boldsymbol{u}_i, \boldsymbol{u}_j \in \boldsymbol{U}_0, \boldsymbol{i} \neq \boldsymbol{j}\}$ is the arc set. Every vertex of $\boldsymbol{U}$ corresponds to a customer to be serviced, and $\boldsymbol{u}_0$ denotes a depot where vehicles are based. With $\boldsymbol{E}$ is associated a travel time matrix $\boldsymbol{T} = (t_{\lambda ij})$, representing the time taken to travel between vertices for truck λ.

Vehicle routing and scheduling with soft time windows (VRPSTW) involves penalties being incurred by freight carriers for deliveries outside of customer-specified time windows (*18*). Here, vehicles incur a penalty proportional to the period of time they arrive outside of customers' time windows. The VRPSTW consists of finding a permutation $\boldsymbol{\pi}$ of the sets $\{\boldsymbol{\lambda}, \mathbf{0}, \mathbf{1}, \ldots, \boldsymbol{N}_\lambda, \mathbf{0}\} : \boldsymbol{\lambda} = \mathbf{1}, \ldots, \boldsymbol{m}$ corresponding to tours that start and end at the depot, i.e., $\boldsymbol{\pi}(\boldsymbol{\lambda}, \mathbf{0}) = \mathbf{0}$

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and $\pi(\lambda, N_\lambda + 1) = 0$, such that every vertex of V is visited exactly once, the capacity of the trucks is not exceeded, and the total routing cost is minimized, where m is the number of trucks available, and N_λ is the number of customers visited by truck $\lambda(\lambda = 1, \ldots, m)$.

For each customer, u_i, the following parameters are specified:

1. Time window (e_i, l_i) where e_i and l_i are the earliest and the latest arrival time, respectively, within which the customer should be visited;
2. Service time $(s_{\lambda,i})$ for loading and unloading the goods from truck λ;
3. Waiting time penalty unit rate, α_i, for arrival before e_i; and
4. Delay time penalty unit rate, β_i, for arrival after l_i.

Although the actual travel time between customers is uncertain in static vehicle routing and scheduling problems, a single value estimate (forecast) is usually made (*19*). Stochastic models allow random inputs that are assumed to follow a probability distribution. This paper presents procedures that allow the variability of travel times between customers to be incorporated within optimization procedures for vehicle routing and scheduling with soft time windows.

FORECAST MODEL

The arrival time of a truck at a customer location depends on the departure time from the previous customer location, as well as the travel time from that customer (Equations 1, 2, and 3).

$$a_{\lambda,\pi(\lambda,i)} = d_{\lambda,\pi(\lambda,i-1)} + t_{\lambda,\pi(\lambda,i-1),\pi(\lambda,i)} \tag{1}$$

where

$a_{\lambda,\pi(\lambda,i)}$ = arrival time of truck λ at customer $\pi(\lambda, i)$,
$d_{\lambda,\pi(\lambda,i-1)}$ = departure time of truck λ from customer $\pi(\lambda, i-1)$,
$t_{\lambda,\pi(\lambda,i-1),\pi(\lambda,i)}$ = travel time of truck λ between customer $\pi(\lambda, i-1)$, and $\pi(\lambda, i)$

$$d_{\lambda,\pi(\lambda,i)} = a_{\lambda,\pi(\lambda,i)} + w_{\lambda,\pi(\lambda,i)} + s_{\lambda,\pi(\lambda,i)} + b_{\lambda,\pi(\lambda,i)} \tag{2}$$

where

$$w_{\lambda,\pi(\lambda,i)} = \text{waiting time of truck } \lambda \text{ at customer } \pi(\lambda, i)$$
$$= \begin{cases} e_{\pi(\lambda,i)} - a_{\lambda,\pi(\lambda,i)} & \text{if } a_{\lambda,\pi(\lambda,i)} < e_{\pi(\lambda,i)} \\ 0 & \text{otherwise} \end{cases}$$

$s_{\lambda,\pi(\lambda,i)}$ = service (loading–unloading) time of truck λ at customer $\pi(\lambda, i)$, $(s_{\lambda,\pi(\lambda,i)}) > 0$), and
$b_{\lambda,\pi(\lambda,i)}$ = break time of truck λ at customer $\pi(\lambda, i)$, including rest and meal periods $(b_{\lambda,\pi(\lambda,i)}) \geq 0$).

Most vehicle routing and scheduling models predict the arrival time of trucks at customer locations deterministically (Equation 3).

$$\boldsymbol{a}_{\lambda,\pi(\lambda,i)} = \boldsymbol{L}_\lambda + \sum_{j=1}^{i} \boldsymbol{t}_{\lambda,\pi(\lambda,j-1)\pi(\lambda,j)} + \sum_{j=1}^{i-1} \left(\boldsymbol{w}_{\lambda,\pi(\lambda,j)} + \boldsymbol{s}_{\lambda,\pi(\lambda,j)} + \boldsymbol{b}_{\lambda,\pi(\lambda,j)} \right) \tag{3}$$

where L_λ is the time vehicle λ left the depot.

The location and activities associated with the distribution of goods for a single truck can be illustrated using a trajectory diagram (Figure 1).

With the VRPSTW, a penalty cost (PC) incurred for early or late arrival at customer location is incorporated into the objective function (Equations 4 and 5).

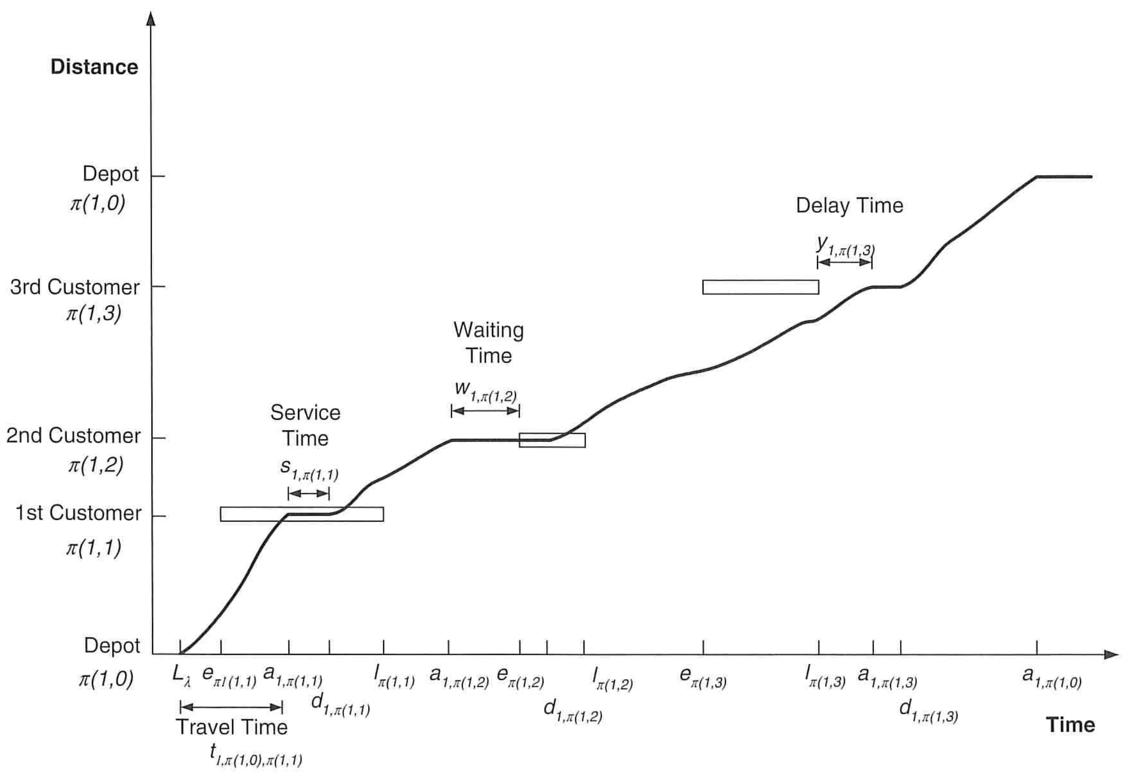

FIGURE 1 Trajectory diagram of vehicle's route.

$$\text{minimize } C(\pi)=\sum_{\lambda=1}^{m}\delta_{\lambda}c_{f,\lambda}+\sum_{\lambda=1}^{m}\sum_{i=0}^{N_{\lambda}}\gamma_{\lambda}t_{\lambda,\pi(\lambda,i),\pi(\lambda,i+1)}+\text{PC} \tag{4}$$

where

$$\delta_{\lambda}=\begin{cases}1 & \text{if vehicle is used}\\ 0 & \text{otherwise}\end{cases}$$

$c_{f,\lambda}$ = fixed cost of truck λ (\$), and
γ_{λ} = operating cost for truck λ (\$/min).

$$\text{PC}=\sum_{\lambda=1}^{m}\sum_{i=1}^{N_{\lambda}}\left(\alpha_{\pi(\lambda,i)}w_{\lambda,\pi(\lambda,i)}+\beta_{\pi(\lambda,i)}y_{\lambda,\pi(\lambda,i)}\right) \tag{5}$$

where

$$y_{\lambda,\pi(\lambda,i)} = \text{delay time of truck } \lambda \text{ at customer } \pi(\lambda,i)$$
$$=\begin{cases}a_{\lambda,\pi(\lambda,i)}-l_{\pi(\lambda,i)} & \text{if } a_{\lambda,\pi(\lambda,i)}>l_{\pi(\lambda,i)}\\ 0 & \text{otherwise}\end{cases}$$

STOCHASTIC PROGRAMMING MODEL

With the stochastic programming model for the VRPSTW, an expected penalty cost (E[PC]) must be estimated (*12*). The expected penalty cost associated with this accounts for the uncertainty of predicting the arrival time of trucks visiting customers (Equations 6–8; Figure 2).

$$\text{minimize } \boldsymbol{C}(\pi)=\sum_{\lambda=1}^{m}\delta_{\lambda}\boldsymbol{c}_{f,\lambda}+\sum_{\lambda=1}^{m}\sum_{i=0}^{N_{\lambda}}\gamma_{\lambda}\bar{\boldsymbol{t}}_{\lambda,\pi(\lambda,i),\pi(\lambda,i+1)}+\boldsymbol{E}[\textbf{PC}] \tag{6}$$

where $\bar{t}_{\lambda,\pi(\lambda,i),\pi(\lambda,i+1)}$ is the mean travel time of truck λ between customer $\pi(\lambda, i)$ and customer $\pi(\lambda, i+1)$.

$$\boldsymbol{E}[\textbf{PC}]=\sum_{\lambda=1}^{m}\sum_{i=0}^{N_{\lambda}}\boldsymbol{E}\left[\textbf{pc}_{\lambda,\pi(\lambda,i)}\right] \tag{7}$$

where

$$\begin{aligned}\boldsymbol{E}\left[\textbf{pc}_{\lambda,\pi(\lambda,i)}\right]&=\int_0^{\infty}\boldsymbol{P}_{a_{\lambda,\pi(\lambda,i)}}(t)\,\textbf{PC}_{\lambda,\pi(\lambda,i)}(t)\,dt\\ &=\int_0^{e}\pi(\lambda,i)\boldsymbol{P}_{a_{\lambda,\pi(\lambda,i)}}(t)\left(e_{\pi(\lambda,i)}-t\right)\alpha_{\pi(\lambda,i)}dt\\ &\quad+\int_{l_{\pi(\lambda,i)}}^{\infty}\boldsymbol{P}_{a_{\lambda,\pi(\lambda,i)}}(t)\left(t-l_{\pi(\lambda,i)}\right)\beta_{\pi(\lambda,i)}dt\end{aligned} \tag{8}$$

since

$$pc_{\lambda,\pi(\lambda,i)}(t)=\begin{cases}\left(e_{\pi(\lambda,i)}-t\right)\alpha_{\pi(\lambda,i)} & \text{for } t<e_{\pi(\lambda,i)}\\ 0 & \text{for } e_{\pi(\lambda,i)}\le t\le l_{\pi(\lambda,i)}\\ \left(t-l_{\pi(\lambda,i)}\right)\beta_{\pi(\lambda,i)} & \text{for } t>l_{\pi(\lambda,i)}\end{cases}$$

where $P_{a_{\lambda,\pi(\lambda,i)}}(t)$ = probability truck λ will arrive at customer $\pi(\lambda, i)$ at time t, ($t \ge 0$) and $pc_{\lambda,\pi(\lambda,i)}(t)$ = penalty cost of truck λ arriving at customer $\pi(\lambda, i)$ at time t, ($t \ge 0$).

A relationship can be determined for estimating the arrival time distribution at a customer's location, assuming that the departure time at the previous customer and the travel time from the previous customer are independent (Equation 9).

$$P_{a_{\lambda,\pi(\lambda,i)}}(k)=\int_0^{\infty}P_{d_{\lambda,\pi(\lambda,i-1)}}(t)\,P\left(t_{\lambda,\pi(\lambda,i-1),\pi(\lambda,i)}=k-t\right)dt \tag{9}$$

where

$P_{a_{\lambda,\pi(\lambda,i)}}(k)$ = probability truck λ will arrive at customer $\pi(\lambda, i)$ at time k, ($k \ge 0$);
$P_{d_{\lambda,\pi(\lambda,i)}}(t)$ = probability truck λ will depart from customer $\pi(\lambda, I-1)$ at time t, ($t \ge 0$); and
$P(t_{\lambda,\pi(\lambda,i-1),\pi(\lambda,i)} = k - t)$ = probability that the travel time between customers $\pi(\lambda, I-1)$ and $\pi(\lambda, i)$ is $(k - t)$ minutes for truck λ ($k > t$).

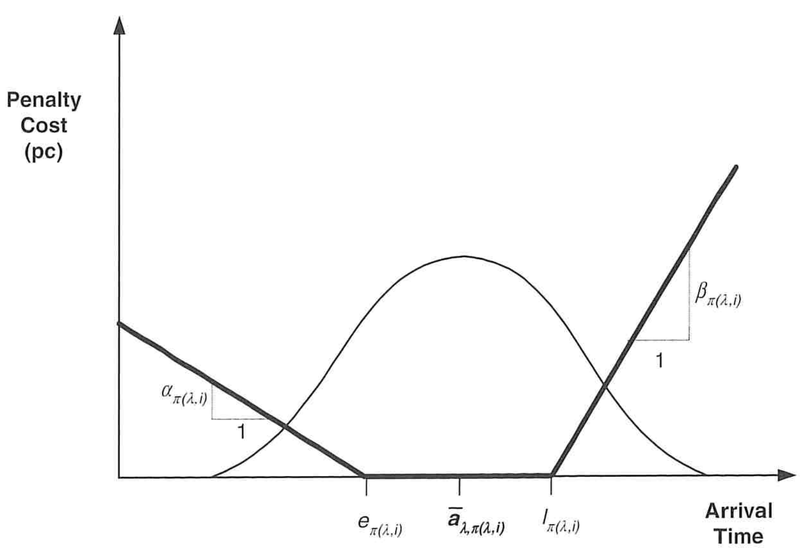

FIGURE 2 Time window and arrival time of truck at customer location.

Although this can be restricted to be within a finite range (Equation 10), it generally requires numerical integration to be used for estimating the arrival time distribution as well as the penalty costs.

$$P_{a_{\lambda,\pi(\lambda,i)}}(k) = \int_A^B P_{d_{\lambda,\pi(\lambda,i-1)}}(t) P\left(t_{\lambda,\pi(\lambda,i-1),\pi(\lambda,i)} = k - t\right) dt \qquad (10)$$

where A is the earliest departure time for truck λ from customer $\pi(\lambda, I-1)$, ($A \geq e_{\pi(\lambda,i-1)} + s_{\lambda,\pi(\lambda,i-1)} + b_{\lambda,\pi(\lambda,i-1)}$), and B is the latest departure time for truck λ from customer $\pi(\lambda, I-1)$.

ARRIVAL TIME DISTRIBUTION

Because the travel times between customers in the probabilistic VRPSTW model are assumed to be stochastic, the arrival time of trucks at customers are also random in nature. However, the nature of the arrival time distribution at a specific customer depends on the distribution of departure times at the previous customer. Because of the presence of soft time windows, the departure time distribution at a customer location depends on the relationship between the arrival time distribution and the earliest start time at that customer location. This is caused by trucks having to wait at customer locations until the earliest customer start time before loading or unloading goods.

Hence, the arrival time distribution at a customer location depends on the departure time distribution at the previous customer location as well as the travel time distribution between customers. There are three general cases (Figure 3).

Case 1

When there is a high probability that a truck will arrive at the previous customer location before the start of the time window at that customer location, the departure time can be considered deterministic. In this case, the arrival distribution at a customer location is normally distributed if the travel time between customers is normally distributed (Equation 11).

Here

$$F_{a_{\lambda,\pi(\lambda,i-1)}}\left(e_{\pi(\lambda,i-1)}\right) > 1 - \omega$$

$$P_{a_{\lambda,\pi(\lambda,i)}}(t) = P\left(t_{\lambda,\pi(\lambda,i-1),\pi(\lambda,i)} = t - \left(e_{\pi(\lambda,i-1)} + s_{\lambda,\pi(\lambda,i-1)} + b_{\lambda,\pi(\lambda,i-1)}\right)\right)$$

where

$$F_{a_{\lambda,\pi(\lambda,i-1)}}(t) = P\left(a_{\lambda,\pi(\lambda,i-1)} < t\right)$$

that is,

$$\bar{a}_{\lambda,\pi(\lambda,i)} = e_{\pi(\lambda,i-1)} + s_{\lambda,\pi(\lambda,i-1)} + b_{\lambda,\pi(\lambda,i-1)} + \bar{t}_{\lambda,\pi(\lambda,i-1),\pi(\lambda,i)}$$

$$\delta^2_{a_{\lambda,\pi(\lambda,i-1),\pi(\lambda,i)}} = \delta^2_{t_{\lambda,\pi(\lambda,i-1),\pi(\lambda,i)}}$$

Now if

$$t_{\lambda,\pi(\lambda,i-1),\pi(\lambda,i)} \sim N\left(\bar{t}_{\lambda,\pi(\lambda,i-1),\pi(\lambda,i)}, \delta^2_{t_{\lambda,\pi(\lambda,i-1),\pi(\lambda,i)}}\right)$$

then

$$a_{\lambda,\pi(\lambda,i)} \sim N\left(e_{\pi(\lambda,i-1)} + s_{\lambda,\pi(\lambda,i-1)} + b_{\lambda,\pi(\lambda,i-1)} + \bar{t}_{\lambda,\pi(\lambda,i-1),\pi(\lambda,i)}, \delta^2_{t_{\lambda,\pi(\lambda,i-1),\pi(\lambda,i)}}\right) \qquad (11)$$

where ω is a small number (e.g., $\omega < 0.01$).

Case 2

Here, there is a significant nonzero probability of the truck arriving both before and after the start of the previous customer's time window, i.e., $F_{a_{\lambda,\pi(\lambda,i-1)}}(e_{\pi(\lambda,i-1)}) > \omega$ and $F_{a_{\lambda,\pi(\lambda,i-1)}}(e_{\pi(\lambda,i-1)}) < 1 - \omega$.

Note that the arrival time at the customer location is not normally distributed for this case, even if the travel times between customers are assumed to be normal. It has a skewed distributed with a longer tail to the right. Larger skewing occurs as the probability of arriving after the start of the time window increases.

The arrival distribution at the previous customer location can be partitioned at the start of the time window of the previous customer. Here, the distribution is truncated to form two arrival distributions, truncated above within the range $[-\infty, e_{\pi(\lambda,i-1)}]$ and truncated below within the $[e_{\pi(\lambda,i-1)}, \infty]$ (Figure 4).

Here, the departure time distribution from the previous customer is a mixture of a discrete and a continuous distribution. In this case, the mean and variance of the arrival time at a customer location can be determined by estimating a weighted mean and variance based on the means and variances of the truncated normal distributions of the arrival time at the previous customer location (Equations 12 and 13) (Figures 5 and 6).

$$\begin{aligned}\bar{a}_{\lambda,\pi(\lambda,i)} = {} & F_{a_{\lambda,\pi(\lambda,i-1)}}\left(e_{\pi(\lambda,i-1)}\right)\left(e_{\pi(\lambda,i-1)} + s_{\lambda,\pi(\lambda,i-1)} + b_{\lambda,\pi(\lambda,i-1)} + \bar{t}_{\lambda,\pi(\lambda,i-1),\pi(\lambda,i)}\right) \\ & + \left(1 - F_{a_{\lambda,\pi(\lambda,i-1)}}\left(e_{\pi(\lambda,i-1)}\right)\right)\left(\bar{a}^{\mathrm{TB}}_{\lambda,\pi(\lambda,i-1)} + s_{\lambda,\pi(\lambda,i-1)} + b_{\lambda,\pi(\lambda,i-1)} \right. \\ & \left. + \bar{t}_{\lambda,\pi(\lambda,i-1),\pi(\lambda,i)}\right)\end{aligned} \qquad (12)$$

$$\begin{aligned}\delta^2_{a_{\lambda,\pi(\lambda,i)}} = {} & F_{a_{\lambda,\pi(\lambda,i-1)}}\left(e_{\pi(\lambda,i-1)}\right)\delta^2_{t_{\lambda,\pi(\lambda,i-1),\pi(\lambda,i)}} \\ & + \left(1 - F_{a_{\lambda,\pi(\lambda,i-1)}}\left(e_{\pi(\lambda,i-1)}\right)\right)\left(\delta^{\mathrm{TB}^2}_{a_{\lambda,\pi(\lambda,i-1)}} + \delta^2_{t_{\lambda,\pi(\lambda,i-1),\pi(\lambda,i)}}\right)\end{aligned} \qquad (13)$$

where $\bar{a}^{\mathrm{TB}}_{\lambda,\pi(\lambda,i-1)}$ = mean arrival time (truncated below) and $\delta^{\mathrm{TB}2}_{a_{\lambda,\pi(\lambda,i-1)}}$ = variance of arrival times (truncated below).

Expressions for estimating the mean and variance of the truncated arrival distributions have been derived using theoretical statistical relationships (*20*) (Equations 14 and 15).

$$\bar{a}^{\mathrm{TB}}_{\lambda,\pi(\lambda,i-1)} = \bar{a}_{\lambda,\pi(\lambda,i-1)} + \left(\frac{Z(z)}{(1-\Phi(z))}\right)\delta_{a_{\lambda,\pi(\lambda,i-1)}} \qquad (14)$$

$$\delta^{\mathrm{TB}^2}_{a_{\lambda,\pi(\lambda,i-1)}} = \left(1 + \frac{zZ(z)}{(1-\Phi(z))} - \left(\frac{Z(z)}{(1-\Phi(z))}\right)^2\right)\delta^2_{a_{\lambda,\pi(\lambda,i-1)}} \qquad (15)$$

where

$z = (e_{\pi(\lambda,i-1)} - \bar{a}_{\lambda,\pi(\lambda,i-1)})/\delta_{\lambda,\pi(\lambda,i-1)}$

$Z(t) = P(t) \ni t \sim N(0, 1)$

$\Phi(t) = F(t) \ni t \sim N(0, 1)$

This method relies on using the means and standard deviations of the truncated distributions. However, numerical integration must be used

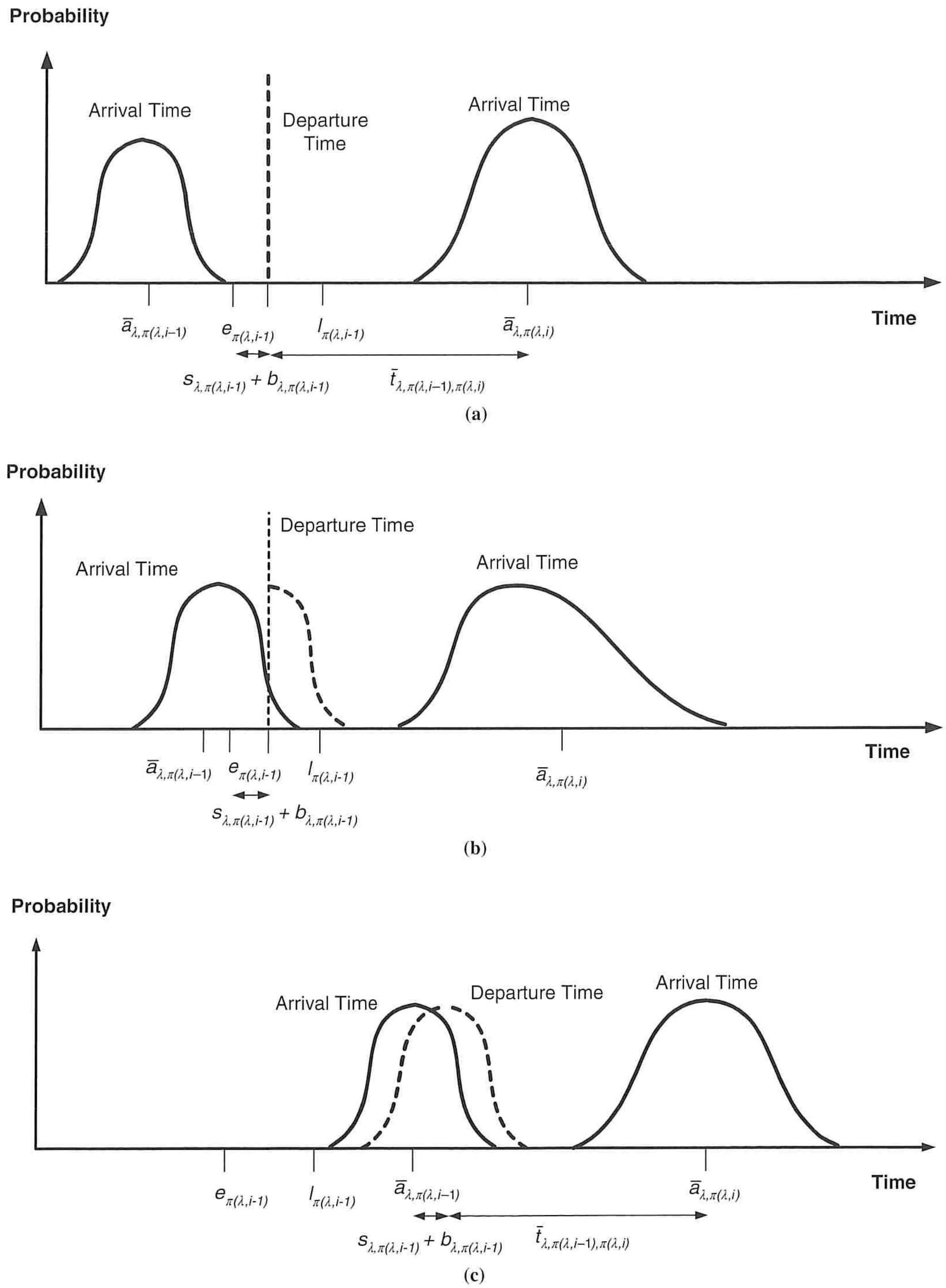

FIGURE 3 Arrival and departure distributions: (*a*) Case 1, (*b*) Case 2, and (*c*) Case 3.

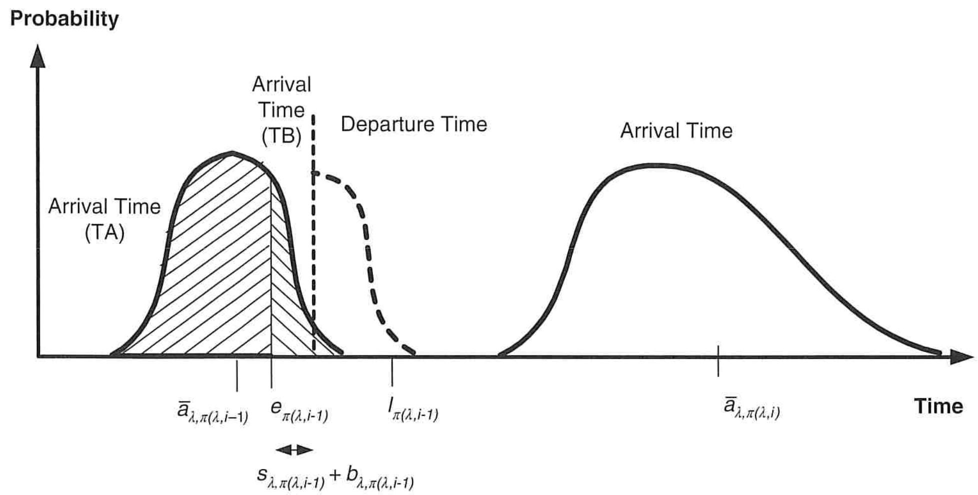

FIGURE 4 Truncated arrival distribution (TA = truncated above; TB = truncated below).

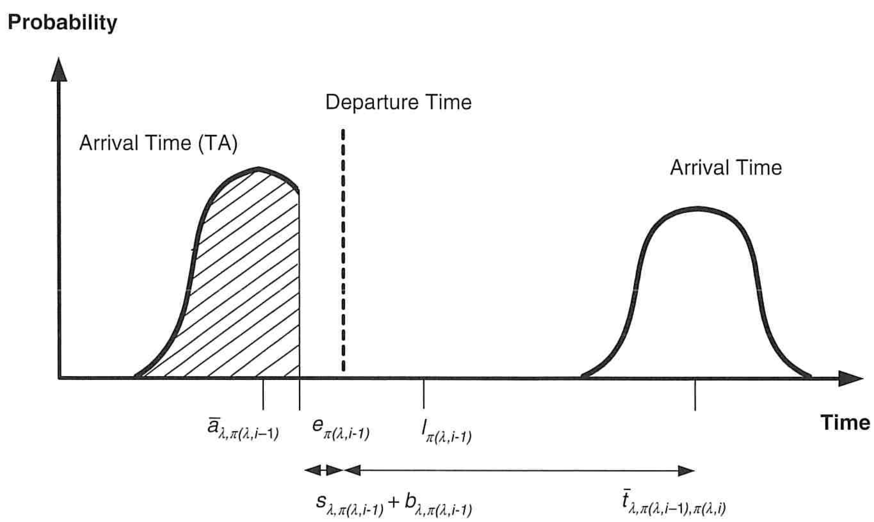

FIGURE 5 Case 2 probability of arriving early.

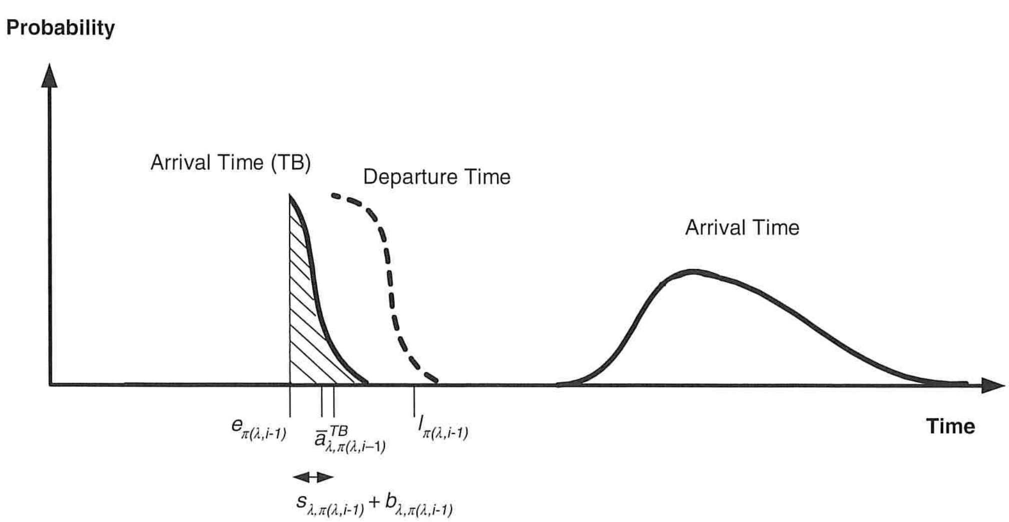

FIGURE 6 Case 2 probability of arriving after start of time window.

to accurately determine the expected penalty cost because of a non-normal arrival time distribution in this case. This is computationally expensive.

Case 3

In this case, there is a low probability that the truck will arrive at the previous customer location before the start of its time window. Here,

$$F_{a_{\lambda,\pi(\lambda,i-1)}}\left(e_{\pi(\lambda,i-1)}\right) < \omega$$

$$P_{a_{\lambda,\pi(\lambda,i-1)}}(t) = \int_{e_{\pi(\lambda,i-1)}}^{\infty} A(\eta) \times T(\lambda)\, d\eta$$

where

$$\begin{aligned}
A(\lambda) &= P_{a_{\lambda,\pi(\lambda,i)}}(\eta) \\
T(\lambda) &= P(t_{\lambda,\pi(\lambda,i-1),\pi(\lambda,i)} = t - (\eta + s_{\lambda,\pi(\lambda,i-1)} + b_{\lambda,\pi(\lambda,i-1)})) \\
\bar{a}_{\lambda,\pi(\lambda,i)} &= \bar{a}_{\lambda,\pi(\lambda,i-1)} + s_{\lambda,\pi(\lambda,i-1)} + b_{\lambda,\pi(\lambda,i-1)} + \bar{t}_{\lambda,\pi(\lambda,i-1),\pi(\lambda,i)} \\
\delta^2_{a_{\lambda,\pi(\lambda,i)}} &= \delta^2_{a_{\lambda,\pi(\lambda,i-1)}} + \delta^2_{t_{\lambda,\pi(\lambda,i-1),\pi(\lambda,i)}}
\end{aligned}$$

Now if

$$t_{\lambda,\pi(\lambda,i-1),\pi(\lambda,i)} \sim N\left(\bar{t}_{\lambda,\pi(\lambda,i-1),\pi(\lambda,i)}, \delta^2_{t_{\lambda,\pi(\lambda,i-1),\pi(\lambda,i)}}\right)$$

then

$$a_{\lambda,\pi(\lambda,i)} \sim N\left(\bar{a}_{\lambda,\pi(\lambda,i-1)} + s_{\lambda,\pi(\lambda,i-1)} + b_{\lambda,\pi(\lambda,i-1)} + \bar{t}_{\lambda,\pi(\lambda,i-1),\pi(\lambda,i)}, \delta^2_{a_{\lambda,\pi(\lambda,i-1)}} + \delta^2_{t_{\lambda,\pi(\lambda,i-1),\pi(\lambda,i)}}\right) \tag{16}$$

In this case, the distribution of the arrival time at a customer location is determined on the basis of the following result: if the travel time between customers is normally distributed, then the resulting arrival time distribution is also normal as the sum of two normally distributed random variables—the departure time at the previous customer and the travel time between customers. Here, the mean arrival time is equal to the sum of the two means, and the variance is equal to the sum of the two variances.

EXPECTED PENALTY COST PROCEDURE

The previous section showed that the normal distribution can be used to represent the arrival times of trucks at customer locations with soft time windows when travel between customer locations are assumed to be normally distributed for Cases 1 and 3. Relationships for estimating the mean and variance of the arrival time distributions were also presented. An expression for estimating the expected penalty cost has been determined using calculus that can be used in these cases (Equation 17).

$$\begin{aligned}
E\left[pc_{\lambda,\pi(\lambda,i)}\right] = \alpha_{\pi(\lambda,i)} &\left\{ F_{a_{\lambda,\pi(\lambda,i)}}\left(e_{\pi(\lambda,i)}\right)\left(e_{\pi(\lambda,i)} - \bar{a}_{\lambda,\pi(\lambda,i)}\right) + \frac{\delta_{a_{\lambda,\pi(\lambda,i)}}}{\sqrt{2\pi}}\left(e^{\frac{-\left(e_{\pi(\lambda,i)} - \bar{a}_{\lambda,\pi(\lambda,i)}\right)^2}{2\delta^2_{a_{\lambda,\pi(\lambda,i)}}}} - e^{\frac{-\bar{a}^2_{\lambda,\pi(\lambda,i)}}{2\delta^2_{a_{\lambda,\pi(\lambda,i)}}}} \right) \right\} \\
&+ \beta_{\pi(\lambda,i)} \left\{ \left(1 - F_{a_{\lambda,\pi(\lambda,i)}}\left(l_{\pi(\lambda,i)}\right)\right)\left(\bar{a}_{\lambda,\pi(\lambda,i)} - l_{\pi(\lambda,i)}\right) + \frac{\delta_{a_{\lambda,\pi(\lambda,i)}}}{\sqrt{2\pi}} e^{\frac{-\left(l_{\pi(\lambda,i)} - \bar{a}_{\lambda,\pi(\lambda,i)}\right)^2}{2\delta^2_{a_{\lambda,\pi(\lambda,i)}}}} \right\}
\end{aligned} \tag{17}$$

ROBUST OPTIMIZATION

Description

Robust optimization (RO) is an alternative approach to stochastic programming that combines goal programming with a scenario-based approach representing the uncertainty of input variables (*21*). A penalty function is added to the objective function that represents the violation of constraints for a range of scenarios for uncertain parameters. Here, the variability of travel time on distribution costs is considered, incorporating time window constraints.

Formulation

If a fixed number of travel time scenarios is considered between customer locations for each arrival time scenario generated at previous customer locations, then the objective function can be formulated by adding an additional term to represent the arrival time penalties associated with time windows (Equation 18).

$$\min z = \sum_{\lambda=1}^{m} \delta_\lambda c_{f,\lambda} + \sum_{\lambda=1}^{m} \sum_{i=1}^{N_\lambda} \gamma_\lambda \bar{t}_{\lambda,\pi(\lambda,i-1),\pi(\lambda,i)} + \frac{1}{\sum_{i=1}^{N} m_i} \sum_{i=1}^{N} \sum_{s \in \Omega_i} \omega_{i,s} P_{i,s} \tag{18}$$

where

$\omega_{i,s}$ = weighting of arrival time penalty for customer i for arrival time scenario s,

$p_{i,s}$ = arrival time penalty at ith customer for arrival time scenario s,

$\Omega_i = \{S_1^i, S_2^i, \ldots, S_{mi}^i\}$
= set of arrival time scenarios at the ith customer,

$$m_i = \sum_{j=1}^{i} o^j$$

= number of arrival time scenarios at the ith customer, and

o = number of travel time scenarios between customers (a constant).

To estimate arrival time penalties at customers, travel time scenarios must be generated.

Let $T_{i-1,i}$ be the set of travel time scenarios between the $(i-1)$th and ith customer $T_{i-1,i} = \{T_1^{i-1,i}, T_2^{i-1,i}, \ldots, T_o^{i-1,i}\}$.

For example, $T_{i-1,i} = \{\bar{tt}_{i-1,i} - 0.2\bar{tt}_{i-1,i}, \bar{tt}_{i-1,i}, \bar{tt}_{i-1,i} + 0.2\bar{tt}_{i-1,i}\}$, where $o = 3$.

However, it is computationally demanding to calculate this for most practical problems because the number of arrival time scenarios at customers increases dramatically after the initial customer in each route. If only a limited number of scenarios are generated, based on a single randomly generated travel time between customers from each departure time at the previous customer then this is not so computationally expensive. The objective function for this approach can be formulated as shown in Equation 19.

$$\min z = \sum_{\lambda=1}^{m} \delta_\lambda c_{f,\lambda} + \sum_{\lambda=1}^{m} \sum_{i=1}^{N_\lambda} \gamma_\lambda \bar{t}_{\lambda,\pi(\lambda,i-1),\pi(\lambda,i)} + \omega \sum_{\lambda=1}^{m} \frac{1}{(nN_\lambda)} \sum_{i=1}^{N_\lambda} \sum_{s \in \Omega_{\pi(\lambda,i)}} \phi_{\pi(\lambda,i)} p_{\pi(\lambda,i),s} \tag{19}$$

--where

ω = weighting of feasibility robustness,
$\phi_{\pi(\lambda,i)}$ = weighting of arrival time penalty for customer $\pi(\lambda, i)$,
$p_{\pi(\lambda,i),s}$ = arrival time penalty at customer $\pi(\lambda, i)$ for arrival time scenario s,
$\Omega_{\pi(\lambda,i)} = \{S_1^{\pi(\lambda,i)}, S_2^{\pi(\lambda,i)}, \ldots, S_n^{\pi(\lambda,i)}\}$ set of arrival time scenarios at customer $\pi(\lambda, i)$, and
n = number of arrival time scenarios.

The arrival time scenarios at each customer location are dependent on the arrival scenarios at the previous customer location, the time windows at the previous customer location, as well as the travel time scenarios between customers.

Let $a^s_{\pi(\lambda,i)}$ = arrival time at customer $\pi(\lambda, i)$ for arrival time scenario s.

Now

$$a^s_{\pi(\lambda,i)} = \begin{cases} e_{\pi(\lambda,i-1)} + s_{\pi(\lambda,i-1)} + t^s_{\pi(\lambda,i-1),\pi(\lambda,i)} & \text{if } a^s_{\pi(\lambda,i-1)} < e_{\pi(\lambda,i-1)} \\ a^s_{\pi(\lambda,i-1)} + s_{\pi(\lambda,i-1)} + t^s_{\pi(\lambda,i-1),\pi(\lambda,i)} & \text{otherwise} \end{cases}$$

where $t^s_{\pi(\lambda,i-1),\pi(\lambda,i)}$ equals travel time to customer $\pi(\lambda, i)$ from customer $\pi(\lambda, i-1)$ for travel time scenario s.

Now

$$t_{\pi(\lambda,i-1),\pi(\lambda,i)} \sim N(\bar{t}_{\pi(\lambda,i-1),\pi(\lambda,i)}, \delta_{\pi(\lambda,i-1),\pi(\lambda,1)})$$

where $\delta_{\pi(\lambda,i-1),\pi(\lambda,i)}$ equals standard deviation of travel time from customer $\pi(\lambda, i)$ to customer $\pi(\lambda, i-1)$ and

$$p_{\pi(\lambda,i),s} = \begin{cases} e_{\pi(\lambda,i)} - a^s_{\pi(\lambda,i)} & \text{if } a^s_{\pi(\lambda,i)} < e_{\pi(\lambda,i)} \\ a^s_{\pi(\lambda,i)} - l_{\pi(\lambda,i)} & \text{if } a^s_{\pi(\lambda,i)} > l_{\pi(\lambda,i)} \\ 0 & \text{otherwise} \end{cases}$$

Now

$$\phi_{\pi(\lambda,i)} = \begin{cases} \alpha_{\pi(\lambda,i)} & \text{if } a^s_{\pi(\lambda,i)} < e_{\pi(\lambda,i)} \\ \beta_{\pi(\lambda,i)} & \text{if } a^s_{\pi(\lambda,i)} > l_{\pi(\lambda,i)} \\ 0 & \text{otherwise} \end{cases}$$

where

$\alpha_{\pi(\lambda,i)}$ = penalty rate for early arrivals at customer $\pi(\lambda, i)$ (\$/min),
$\beta_{\pi(\lambda,i)}$ = penalty rate for late arrivals at customer $\pi(\lambda, i)$ (\$/min), and
$\alpha_{\pi(\lambda,i)} \le \beta_{\pi(\lambda,i)}$, and $\alpha_{\pi(\lambda,i)}, \beta_{\pi(\lambda,i)} \ge 0$.

This formulation provides a practical method, in terms of computational burden, of incorporating travel time variations between customers for the VRPSTW.

BENEFIT ANALYSIS

The value of the stochastic solution measures the possible gain from solving a stochastic model that explicitly incorporates the distribution of random variables within the problem formulation (*22*). It represents the value of knowing and using the distributions of future outcomes. The value of the stochastic solution is relevant to problems where the future is uncertain and no further information about the future is available. It measures the cost of ignoring uncertainty when making a decision (i.e., determining a solution).

A two-stage procedure was adopted for estimating the benefits (cost savings) of using the previously defined RO model. The first stage involves determining the optimal routes and schedules for both the forecast and RO models. A number of network factors are typically used for estimating travel times between customers, including the geometry of links used between customer locations, temporal demand, and weather conditions. This may also be supplemented with previous experience. This process allows network factors as well as experienced travel times to directly influence the travel times input to both models. Here, a different representation of travel times is used to determine the optimal routes and schedule for each model. The forecast model relies only on a single estimate of travel time between customers, while the RO model requires a distribution of travel times.

The second stage of the process involves testing the performance of the optimal solutions (routes and schedules) produced by both the forecast and RO models under predicted travel time conditions. Here, travel times were generated and the performance of the optimal routes and schedules evaluated using simulation. A costs model was then used to estimate the value of the RO method by comparing the predicted costs of using both types of optimization models.

CASE STUDY

A hypothetical distribution problem is presented here to illustrate how the above procedures can be used to estimate the benefits of using the RO model. The problem involves delivering medical supplies from a warehouse to 20 major hospitals in metropolitan Melbourne (Figure 7). Each hospital requires 100 kg of medical products to be delivered within specific time windows (Table 1). Two vans are available, each with a storage capacity of 1,000 kg.

The optimal routes and schedules were determined for both the forecast and RO models using the tabu search metaheuristic technique (*18*). The cross exchange neighborhood generation method provided an efficient means of identifying optimal solutions. The values of the cost items for this problem are given in Table 2. Based on surveys, a number of parameters were used to estimate the travel time between customer locations for the forecast model (Table 2). Driver break times were set to zero and were assumed to

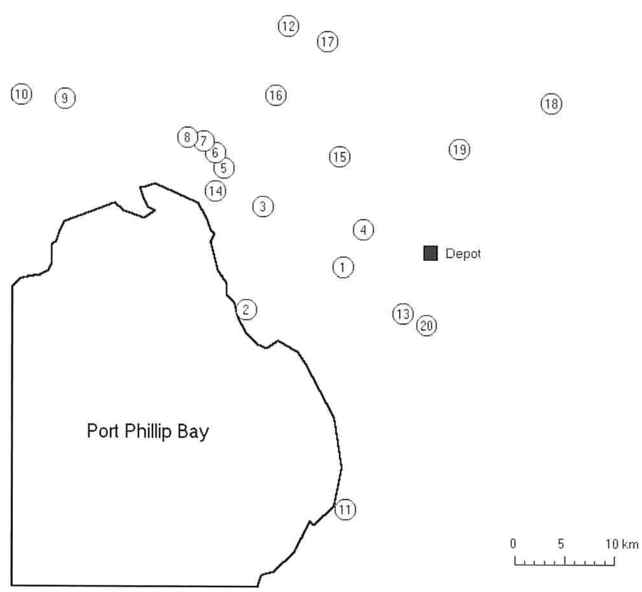

FIGURE 7 Location of major hospitals in Melbourne.

TABLE 1 Customer Time Windows

Number	Name	After	Before
1	Monash Medical Centre	09:00	10:00
2	Sandringham	08:00	09:00
3	Cabrini	12:30	13:30
4	Waverley	11:00	12:00
5	Epworth	09:00	10:00
6	Mercy	14:30	15:30
7	Royal Womens	14:00	15:00
8	Royal Childrens	10:00	11:00
9	Sunshine	14:00	15:00
10	Western	13:00	14:00
11	Frankston	14:30	15:30
12	North Park	11:00	12:00
13	South Eastern	09:00	10:00
14	Alfred	08:00	09:00
15	Box Hill	10:00	11:00
16	Austin	15:00	16:00
17	Diamond Valley	10:00	11:00
18	Lilydale	12:00	13:00
19	Maroondah	11:30	12:30
20	Dandenong	15:00	16:00

be taken at customer locations, either while waiting or unloading goods, because this is common in urban distribution. A diversion factor was used to convert the direct distance between customer locations to travel distances. For the RO model, the forecast travel time estimates between customers was used to estimate the mean travel time, while the standard deviation (estimated to be 10% of

TABLE 2 Model Parameters for Determining Optimal Solutions

Truck running cost (A$/h)	50
Waiting time penalty rate (A$/h)	50
Delay time penalty rate (A$/h)	250
Diversion factor	1.25
Travel speed (off peak)	45 km/h
Travel speed (peak)	30 km/h

the mean travel time) was used to determine the optimal route and schedule.

The optimal solutions incurred similar costs when the initial travel time parameters used for determining them were realized. The RO model's solution has marginally lower total costs and shorter distance traveled by the vans. Under these travel time conditions, there were no delay costs for the optimal solutions for either model. When comparing the optimal solutions for each method, the total costs were similar [Australian (A) $982.93 for the forecast and A$972.91 for the RO model (A$1 = US$1.03 in 2011)] but the travel distance was lower for the RO model (391.4 km) than the forecast model (420.0 km).

When the initial travel time parameters were used, analysis of the trajectory diagrams of optimal solutions from each model reveals that vans tend to arrive more toward the start of the designated time windows using the optimal solution of the RO model compared with that of the forecast model in these conditions (Figures 8 and 9). Thus, increased travel times between customers would lead to larger delay penalties being incurred when the optimal route of the forecast model is used compared with use of the RO model.

Using the process defined in Figure 8, the performance of both optimal solutions was tested when changes in travel speeds were simulated. Here, travel times between customers were generated using

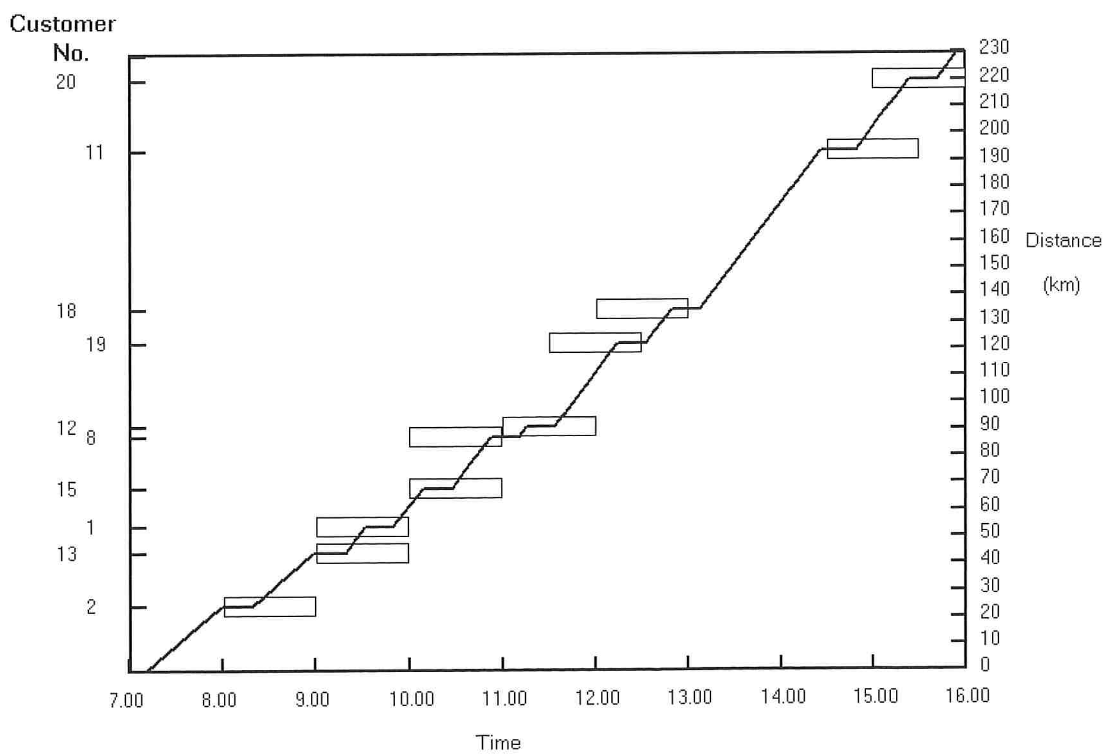

FIGURE 8 Optimal route from forecast model for Van 2

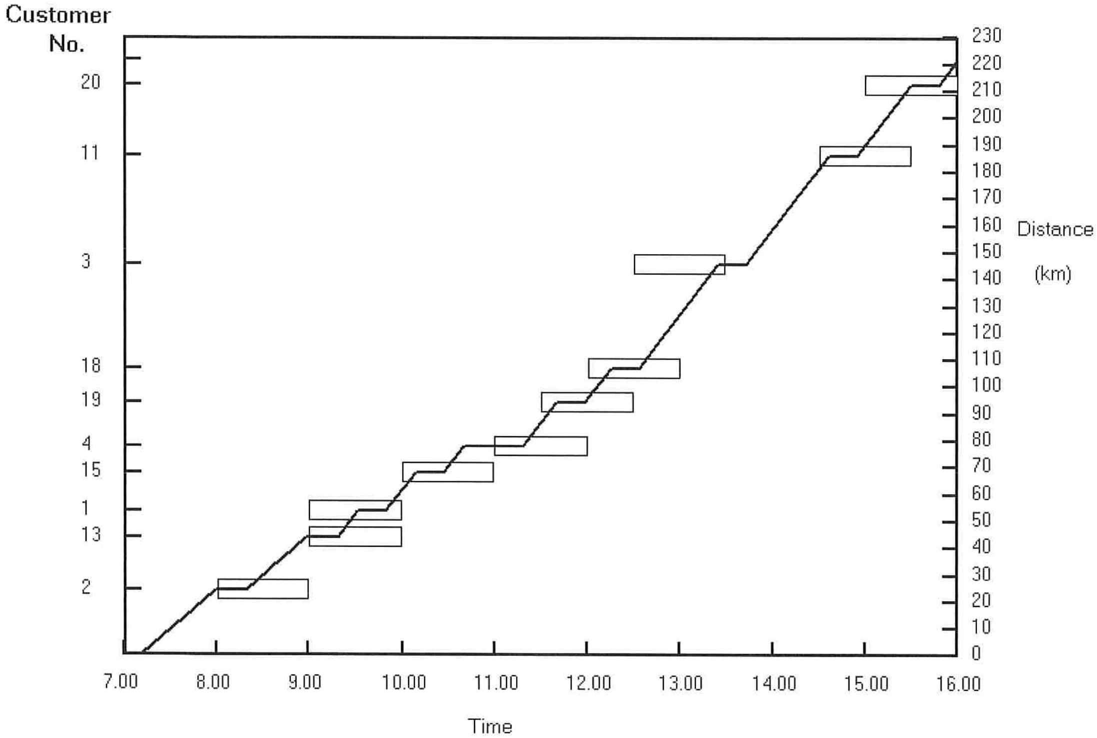

FIGURE 9 Optimal route from RO model for Van 2.

Monte Carlo simulation. A total of 100 runs were used to determine the average costs at each level. The effects on transport costs were estimated when the mean travel speeds were varied. The normal distribution was used to generate travel times between customers with the standard deviation being 10% of the mean at each level.

The performance of the optimal solutions produced by both models are similar when mean travel speeds between customers are increased. However, a reduction in delay time penalties is experienced for optimal solution produced by the RO model when the mean travel speeds are reduced. It can be seen that the RO model's solution achieves significant savings in costs when the decrease in mean travel speed is more than 20% (Figure 10). The highest savings, in percentage terms, are achieved when mean travel speeds are reduced by 30%. Lower savings in percentage terms are achieved with lower mean travel speeds, because at these levels both models generate large penalty costs. Thus, the optimal solution from the RO model performs much better under conditions that are moderately more congested than those used to determine the optimal solutions from both models.

CONCLUSIONS

This paper presents relationships that allow expected penalty costs to be estimated for the vehicle routing problem with time windows, when travel times between customers are assumed to be normally distributed. Combined with recent developments in optimization procedures such as the tabu search metaheuristic, this enables the RO model to be used in practical situations. A case study was used to illustrate the savings that would be achieved when using the RO

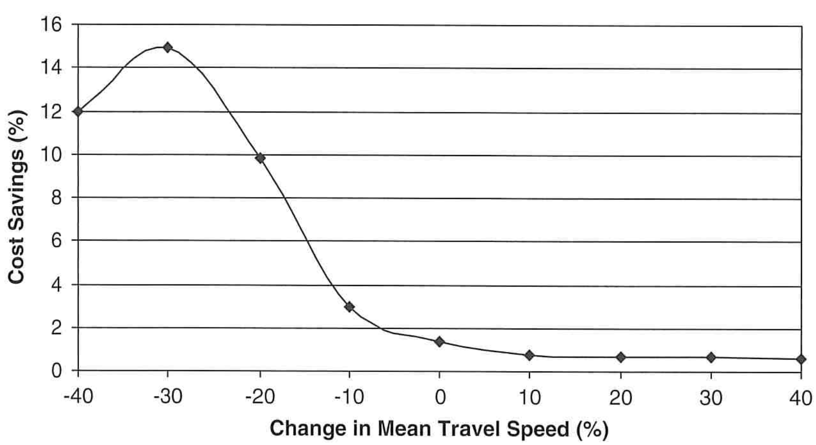

FIGURE 10 Percentage cost savings.

model for delivering goods to customers having time windows in urban areas. Larger benefits were estimated for conditions moderately more congested than those used to determine the optimal solutions. Significant overall savings were estimated by using the optimal solution from the RO model. Increased levels of service for receivers of goods were experienced in the form of lower delay times attributable to the RO model's solution being less sensitive to changes in travel time conditions.

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The Urban Freight Transportation Committee peer-reviewed this paper.

TRANSPORTATION RESEARCH RECORD: JOURNAL OF THE TRANSPORTATION RESEARCH BOARD

Peer Review Process

The *Transportation Research Record: Journal of the Transportation Research Board* publishes approximately 25% of the more than 3,900 papers that are peer reviewed each year. The mission of the Transportation Research Board (TRB) is to disseminate research results to the transportation community. The Record series contains applied and theoretical research results as well as papers on research implementation.

The TRB peer review process for the publication of papers allows a minimum of 30 days for initial review and 60 days for rereview, to ensure that only the highest-quality papers are published. At least three reviews must support a committee's recommendation for publication. The process also allows for scholarly discussion of any paper scheduled for publication, along with an author-prepared closure.

The basic elements of the rigorous peer review of papers submitted to TRB for publication are described below.

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Papers may be submitted to TRB at any time. However, most authors use the TRB web-based electronic submission process available between June 1 and August 1, for publication in the following year's Record series.

Initial Review: August 15–November 15

TRB staff assigns each paper by technical content to a committee that administers the peer review. The committee chair assigns at least three knowledgeable reviewers to each paper. The initial review is completed by mid-September.

By October 1, committee chairs make a preliminary recommendation, placing each paper in one of the following categories:

1. Publish as submitted or with minor revisions,
2. Publish pending author changes and rereview, or
3. Reject for publication.

By late October, TRB communicates the results of the initial review to the corresponding author indicated on the paper submission form. Corresponding authors communicate the information to coauthors. Authors of papers in Category 2 (above) must submit a revised version addressing all reviewer comments and must send an e-mail to the chair or peer review coordinator, explaining how the concerns have been addressed.

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The committee chair reviews revised papers in Category 1 (above) to ensure that the changes are made and sends the Category 2 revised papers to the initial reviewers for rereview. After rereview, the chairs make the final recommendation on papers in Categories 1 and 2. If the paper has been revised to the committee's satisfaction, the chair will recommend publication. The chair communicates the results of the rereview to the authors.

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Discussions may be submitted for papers that will be published. TRB policy is to publish the paper, the discussion, and the author's closure in the same Record.

Many papers considered for publication in the *Transportation Research Record* are also considered for presentation at TRB meetings. Individuals interested in submitting a discussion of any paper presented at a TRB meeting must notify TRB no later than February 1. If the paper has been recommended for publication in the *Transportation Research Record*, the discussion must be submitted to TRB no later than April 15. A copy of this communication is sent to the author and the committee chair.

The committee chair reviews the discussion for appropriateness and asks the author to prepare a closure to be submitted to TRB by May 15. The committee chair reviews the closure for appropriateness. After the committee chair approves both discussion and closure, the paper, the discussion, and the closure are included for publication together in the same Record.

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In early February, TRB requests a final manuscript for publication—to be submitted by March 15—or informs the author that the paper has not been accepted for publication. All accepted papers are published by December 31.

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